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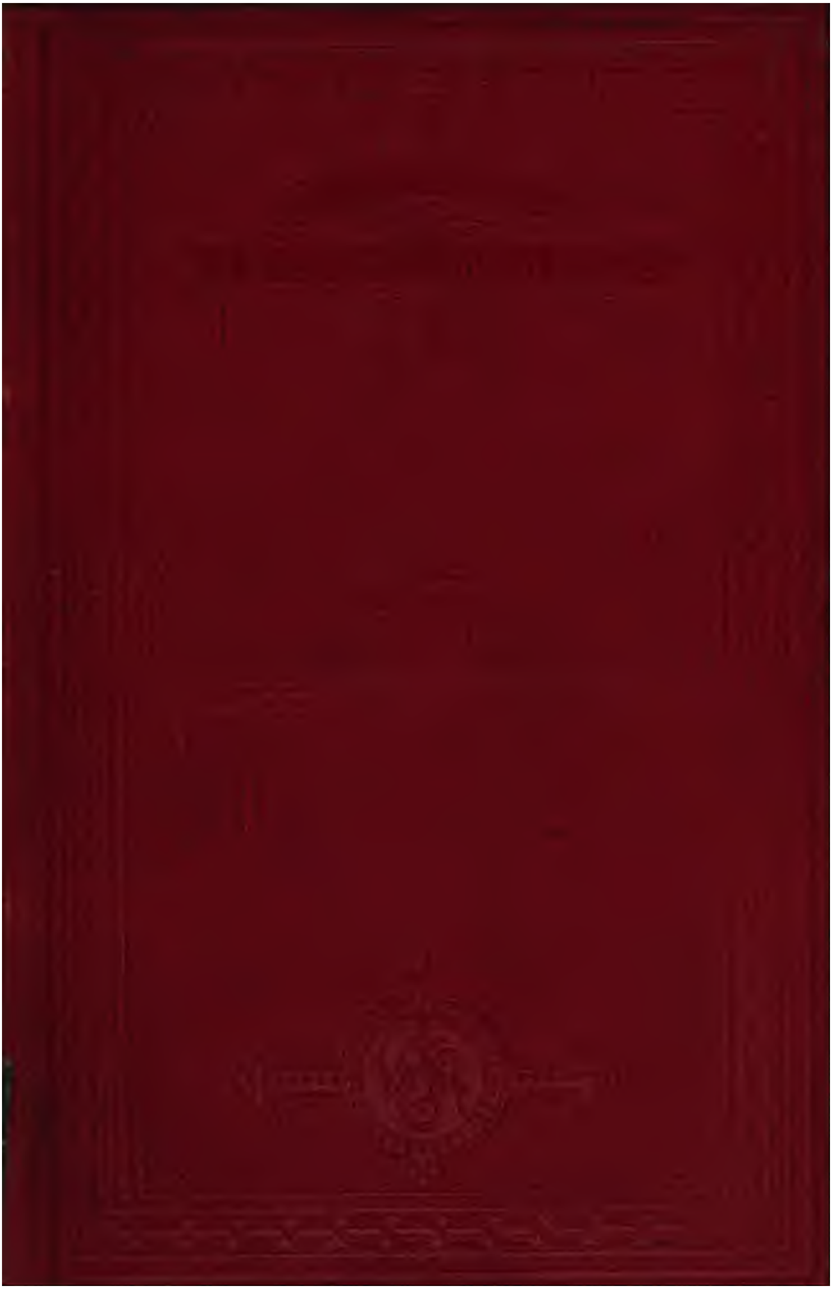

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MAGNETISM AND ELECTRICITY

BY

JOHN COOK, M.A.

LATELY ASSIST. PROF. NAT. PHIL., ABERDEEN UNIVERSITY

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PREFACE.

THE vital importance of diffusing some knowledge of the leading principles of Science among all classes of society, is becoming daily more widely and deeply felt; and to meet and promote this important movement, W. & R. CHAMBERS have resolved on issuing the present Series of ELEMENTARY SCIENCE MANUALS. The Editors believe that they enjoy special facilities for the successful execution of such an undertaking, owing to their long experience—now extending over a period of forty years—in the work of popular education, as well as to their having the co-operation of writers specially qualified to treat the several subjects. In particular, they are happy in having the editorial assistance of ANDREW FINDLATER, LL.D., to whose labours they were so much indebted in the work of editing and preparing *Chambers's Encyclopædia.*

The Manuals of this series are intended to serve two somewhat different purposes:

1. They are designed, in the first place, for SELF-INSTRUCTION, and will present, in a form suitable for private study, the main subjects entering into an enlightened education; so that young persons in earnest about self-culture may be able to master them for themselves.

2. The other purpose of the Manuals is, to serve as TEXT-BOOKS IN SCHOOLS. The mode of treatment naturally adopted in what is to be studied without a teacher, so far from being a drawback in a school-manual, will, it is believed, be a positive advantage. Instead of a number of abrupt statements being presented, to be taken on

trust and learned, as has been the usual method in school-teaching; the subject is made, as far as possible, to unfold itself gradually, as if the pupil were discovering the principles himself, the chief function of the book being, to bring the materials before him, and to guide him by the shortest road to the discovery. This is now acknowledged to be the only profitable method of acquiring knowledge, whether as regards self-instruction or learning at school.

ELECTRICITY, the subject of the present Manual, has within comparatively recent times risen from being little more than a curiosity among natural phenomena to the position of one of the most valuable of natural agencies for the varied wants of mankind, and every one possessed of a liberal education is expected, at the present day, to know the leading facts of its magical power. The ramifications of the *Electric Telegraph* through every portion of the civilised world have so familiarised the present generation of men with its wonders, that they are in danger of forgetting from what humble beginnings the science has sprung. In this Manual the historical growth of the science has been made the index to the order of its exposition; and care has been taken to avoid all mathematical expressions, or calculations which are not of the most elementary character.

For simplification in teaching, the subject has been divided into sub-sections or articles, which are numbered continuously; and a series of Questions, in corresponding divisions, has been appended. These Questions, while they will enable the private student to test for himself how far he has mastered the several parts of the subject as he proceeds, will serve the teacher of a class as specimens of the more detailed and varied examination to which he should subject his pupils.

EDINBURGH,
June 1875.

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MAGNETISM.

1. THERE is a kind of greyish-black iron-stone, found in several parts of the world, that has the remarkable property of attracting small pieces of iron or steel. In olden times the Greeks, and probably also the Chinese, knew of this stone. It is said that the Greeks got it from Magnesia, in Asia Minor, and that this is the origin of our terms *magnet* and *magnetism*. The ore is commonly called loadstone, but it is known to chemists as the magnetic oxide of iron.

Not only does the loadstone possess this power of attracting iron itself, but it can communicate its virtue to steel. A bar of well-tempered steel, if repeatedly rubbed by it, acquires exactly similar properties, and is termed an *artificial magnet*, while the other is called a *natural magnet*. In point of strength and convenience, artificial magnets are far superior to natural ones, and are therefore more commonly used.

2. *Poles of a Magnet.*—If we take a bar of steel, which has been thus rubbed by a loadstone, and to which the name of *bar-magnet* is usually given, and scatter iron filings over it, they will adhere in tufts at both ends, but none will be found at the middle of the bar. Or we may put the magnet under a sheet of pasteboard, and sprinkle the filings over the sheet. We shall then find the small particles of iron arrange themselves in beautiful curved lines round both ends of the magnet. It appears from this that the chief power of the bar lies at the two ends, or at points near the ends, round which, as centres, the curves are formed.

These centres of magnetic force are called the *poles* of the loadstone or magnet, from another peculiar property which they are found to possess. If a magnetic bar be suspended by a thread, or be delicately poised on a pivot, it will not rest till it has settled in one position, which is in a direction nearly north and south. If moved from this position, it returns to it again, the *same end* always turning towards the north. That end which so points to the north is called the north pole of the magnet, and the other its south pole.

3. *Poles found only in Pairs.*—We can never have a magnet with only one pole. The two are always found together, and are opposite both in their properties and position. If we break a magnet in two, we do not have two pieces, one all north pole, and the other all south; but we have two complete magnets, and that however many times we break the bar. To this twin exhibition of force residing in opposite sides of a body is given the name of *polarity*. We shall find that it is not peculiar to magnetism, but is a feature of all electric phenomena. Sometimes, indeed, we have in the same bar more than *one pair* of poles; but this is owing to some irregularity of the steel temper, or of the mode in which the magnetism has been communicated. When more than one pair of poles occur in a magnet, they are called *consecutive* points. They render a magnet practically worthless.

4. *Laws of Polar Action.*—The action of the poles of one magnet on those of another is remarkable. If we bring two north poles together, they repel each other; or, if we bring two south poles together, they do the same. But if we bring a north near to a south pole, they attract each other powerfully, and cling together. From this simple experiment we deduce the two general laws of magnetic action: *Like poles repel each other; unlike, attract each other.* It is thus very easy to tell the north and south pole of any magnet. We have simply to try its action on a needle suspended so as to point north and south.

5. *Magnetic Induction.*—A bar of soft iron has of itself no power to attract iron filings, or another piece of iron. In presence of a magnet, however, it instantly assumes this power. If we suspend from, say, the south pole of a magnet an iron nail, its free end attracts filings, just as the magnet would do, and the nail has become, in every way, like a magnet. It has two poles, that end being a north pole which

is next the south pole of the magnet. The same thing is seen, though in a less powerful degree when the magnet is simply brought near to the iron nail. But the magnetisation of the nail, though perfect, is merely temporary. The moment we take away the magnet, its magic power is gone, and the filings drop off.

This action of a magnet on soft iron, communicating to it a temporary magnetic polarity, is termed *induction*. All bodies, as we shall see under *diamagnetism*, are magnetic—that is, influenced by magnetism in one way or another. But induction proper, by which two magnetic poles are excited, is confined to iron and its varieties. Even here there is a remarkable contrast. The influence of a magnet on tempered steel is very different from that on soft iron. Steel will not assume the polar state at once, but only after repeated friction with a magnet. Yet, once magnetised, it retains its polarity with equal stubbornness. The cause of this is not well understood ; but it is usually ascribed to the presence with the particles of steel of a *coercitive force*, as it is called, which resists equally the communication and the abstraction of the magnetic state.

Induction, or the action of a polarised body inducing a similar polarised state of another body in its vicinity, is not confined to magnetism, but appears to be manifested in every case of polarity. We shall see, under Electricity, a similar influence possessed by a body electrically excited or polarised.

6. *Forms of Magnets.*—Magnets are usually made either as straight bars, or like a horse-shoe, so that both poles may be brought to act on the same object. And when powerful magnetism is desired, it is better not to increase the mass of the magnet, but to form a *magnetic magazine*, or *compound magnet*. This is done by magnetising separately a number of similar bar or horse-shoe shaped pieces of steel, and binding

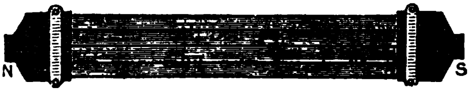

Fig. 1.

them together with the like poles lying the same way. Fig. 1 shews the mode of arrangement of a compound bar-magnet. The bars are bound by a brass screw or frame to a piece of iron at each end, in which the several poles have their magnetism concentrated. Fig. 2 represents a compound horse-shoe magnet, with its armature attached. This armature or keeper must be used with all magnets, to prevent the loss and ultimate disappearance of their magnetism. It is simply a piece of soft iron placed across the opposite poles of a horse-shoe magnet, or of a pair of bar-magnets. Any magnet, not shielded by its armature, has its polarity disturbed and even destroyed by the action of the earth, which is itself an enormous magnet. The soft iron is made, by induction, an exact counterpart of the magnet, and the power of the permanent poles is in this way even increased, for a much greater weight can be suspended from the armature than the single poles can sustain.

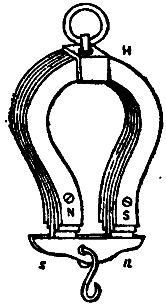

Fig. 2.

7. *Magnetisation.*—There are several processes by which a bar of steel may be magnetised. The simplest way is to pass one pole of a strong magnet from end to end of the bar several times, and always in the same direction. In this case the magnetism of the end first touched will be the same as that of the rubbing pole.

A somewhat better way is to rub the steel bar from the middle to one end with one pole, say the north, of the magnet, and then from the middle to the other end with the south pole. Each half is to be rubbed the same number of times, and the end rubbed by the *north* pole becomes a *south* pole.

Another, and a very accurate method is that shewn in fig. 3, which is employed for magnetising needles. It is called the method by *Divided Touch.* The bar, *ns*, to be magnetised, is placed on a piece of wood, W, with its ends resting on the opposite poles of two strong bar-magnets, NS and SN. Two rubbing magnets are placed, with their opposite poles together, at the middle of *ns*, and making a small angle with it. They are then moved away from each other to the ends of *ns*, and brought back in an arch to the middle again. If this is done a few times, the bar is fully magnetised, the positions of the various poles being indicated by the letters in the figure.

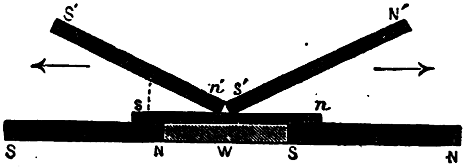

Fig. 3.

For horse-shoe magnets, the usual method is to place the inducing magnet upright on the magnet to be formed, with an armature across its ends, as drawn in fig. 4. It is then moved from the ends to the bend, or in the opposite way, and brought round again in an arch to the starting-point.

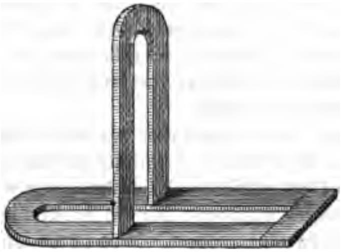

Fig. 4.

Other methods of magnetising steel, which do not require the aid of a magnet, are furnished by the magnetic power of the earth, and by the galvanic current. But these will be explained afterwards.

8. Magnets, when freshly magnetised, have often more magnetism than they can retain. In that case, they gradually fall off in strength until they reach a stationary point, when

they are said to be *saturated.* The strength of magnetism that can be imparted permanently to any magnet, or its saturation point, depends on the quality and temper of its steel. If a magnet has got weakened, its strength may be gradually restored by hanging weights to its armature, and increasing them gradually from time to time. On the other hand, by repeatedly detaching the keeper abruptly, we weaken the power of a magnet, and in this way it is very easy to reduce one above saturation to its fixed strength. It may be remarked generally, that whatever disturbs the molecular condition, or internal state of the particles of a magnet, affects its power. A red heat will deprive it of all traces of magnetism; and a blow, or a number of blows, may do the same, or may even change the poles.

9. *Theories of Magnetism.*—The best known theory of magnetism supposes that there are two magnetic fluids existing in the substance of the magnet, and adhering to it. Each kind of fluid repels itself, but attracts the other kind. In an unmagnetised body, the two fluids are supposed to be mixed up together, and so to counteract each other's effects. Magnetisation consists, according to this view, in separating the two fluids to opposite sides of the body, or to opposite sides of each particle of the body.

Another more recent and more plausible theory regards a magnet as an assemblage of minute permanently magnetic particles, with their similar poles all lying one way. We have seen that, though a magnetic bar be broken into fragments, each piece is a perfect magnet. This fact is supposed to be a strong argument in favour of the latter theory. To magnetise a body is to throw its particles into a state of *regular* polarity, its previous want of magnetism being due to the want of this *regularity.*

Ampere's theory, which connects the phenomena of magnetism and of electricity, is another and still more novel theory, which will be explained under Electro-magnetism.

10. *Diamagnetism.*—It had been known since the beginning of this century that the metals nickel and cobalt were feebly magnetic, and could be attracted by a strong steel magnet. But the effect of magnetism on other bodies was unknown

till the discovery of an unlimited magnetic power in the galvanic current. The electro-magnet (to be afterwards described) was used in the hands of Faraday, to shew that all bodies are more or less magnetic; though, in general, the magnetism is so feeble as to be utterly insensible to the most powerful steel magnet. Faraday, in 1845, first proved that all the metals, such as gold, silver, copper, etc., as well as the liquids and gases, are influenced by the powerful magnetism of the electro-magnet. He also established, by a series of beautiful experiments, that there is a notable difference in its effects on different bodies.

If a small piece of iron wire be hung by a silk fibre between the poles of an electro-magnet (fig. 5), it will come to rest with its length in the line of the poles, *ab*, or *axially*, as Faraday termed it.

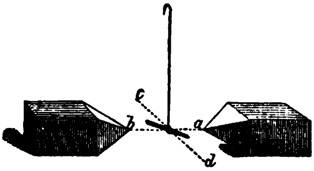

Fig. 5.

But if a small rod of bismuth be suspended in this way, it will set with its length along *cd*, that is, across the line of the poles, or *equatorially*. The reason is, that iron is attracted by both poles, while bismuth is repelled by both. Iron, and substances which behave like it, Faraday called *paramagnetic;* bismuth, and those like it, he called *diamagnetic*. Ordinary magnets are sufficient to shew the paramagnetism of iron, nickel, and cobalt; but the coercitive force of other substances is so feeble that they require a much more powerful magnetism. The following substances are found to be paramagnetic: *Iron*, *nickel*, *cobalt*, *manganese*, *paper*, *sealing-wax*, *plumbago*, *red lead*, *zinc-sulphate*, *shellac*, *charcoal*. These are diamagnetic: *Bismuth*, *antimony*, *zinc*, *tin*, *mercury*, *lead*, *silver*, *copper*, *gold*, *alum*, *glass*, *nitre*, *sulphur*, *resin*, *water*, *wood*, *leather*, *caoutchouc*. They are given in the order of their coercitive force. By inflating soap-bubbles with different gases, Faraday proved that gases also are magnetic, though to a much feebler degree than any solid or liquid substances.

TERRESTRIAL MAGNETISM.

11. Our earth is an immense magnet, with its two magnetic poles situated *towards* the north and south ends of its axis. This is the cause that a magnetised needle, delicately poised, as shewn in fig. 6, takes up a position nearly north and south. The distances of the earth's poles are so great that their actions on the poles of the needle may be regarded as equal forces acting in opposite ways. Such forces can have no other effect than merely to turn the needle round its axis, so as to have its length in their direction. For this reason, a common steel needle, magnetised and made to swim on water, will shew no tendency to move either towards the north pole of the earth or towards the south, but will simply set in their line.

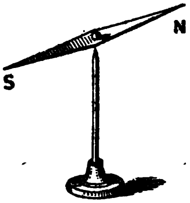

Fig. 6.

The value of the magnetic needle as a guide, in the absence of other directing marks, is obvious. To the navigator it is inestimable, and led, centuries ago, to the invention of the *mariner's compass.*

12. *Declination.*—But the needle does not point *due* north and south, and the amount by which it deviates from that direction is called the *declination* of the needle. The reason of this deviation is, that the magnetic poles of the earth are not at the ends of its axis, just as the poles of a common steel magnet are not at its ends precisely.

It is of the utmost importance to the mariner to know the amount of this deviation of his needle, or compass, from the true north; and what makes the indications of his guide less reliable is the fact, that the declination is not the same for all places on the earth's surface. In some places, there is no declination at all—that is to say, the needle points due north. In this country, it points to the *west* of true north, while in India it is found to point to the east of it.

Charts have been drawn having these important changes accurately marked by lines traced through all places where the amount of declination is the same. These lines are called *isogonic* or *equal-angle* lines, and the charts *isogonic charts.* Looking at such a chart, we see that the needle points to the *west* of the true north in *Europe* and *Africa*, in the *Atlantic Ocean*, in the *eastern part of the two Americas*, and *the western part of Asia and Australia.* These form what may be called the western declination hemisphere, while the other parts of the earth's surface form the eastern. An irregular line of no declination separates the two hemispheres, running through the eastern continent of North America, and a corner of South America, and coming round through Australia, the west of Asia, and the east of Russia. Curiously enough, the line is slowly changing place, the Asiatic line of no declination advancing towards Europe.

13. *Periodical Variations of the Compass.*—Nor does the declination vary only with the place on the earth's surface, but, at the same place, it varies with the *year*, the *season of the year*, and even the *hour.* In England, for instance, the needle had been for 170 years turning more and more to W. of true north, till in 1815, it was as much as 24½° W. Every year since then it has been slowly receding, and now it is only about 19½° W. At the present annual rate of decrease (8′), it will within a century and a half once more point due north.

There is also a periodical variation with the season of the year. Observations shew that, from April to July, the amount of westerly declination decreases; while, during the rest of the year, there is a slight turning to the west.

The needle shews a slight, yet quite decided tendency to turn to the sun, and this gives rise to regular daily fluctuations. Of course the motion is very minute, and requires very delicate instruments and observations to detect it.

Besides these *regular* variations of the declination, there are sudden and unforeseen disturbances, caused by what are called *magnetic storms.* Earthquakes and volcanic eruptions have a marked effect on the needle. The Aurora Borealis is invariably accompanied by its disturbance; and the appearance of solar spots, which are most numerous every ten years, has been associated with special magnetic irregularities.

14. *Inclination or Dip.*—If an unmagnetised needle be

balanced about an axis, so as to remain horizontal, it will, after being magnetised, and placed in the magnetic meridian, no longer lie evenly, but will *point downwards*. This *dip* or *inclination*, as it is termed, of the needle to the horizontal is owing to the position of the earth's magnetic poles. They are deep in the interior of the globe, and by no means coincide with the poles of its axis. Now, if we take a small balanced needle which can swing vertically up and down, and move it over a bar-magnet, we find that when it is above the middle of the bar, it remains horizontal, its ends being equally attracted by the poles of the magnet. When brought over one of the poles, it stands upright, and at any position between, it is more or less in an inclined direction. Exactly similar to the action of the bar-magnet is that of the earth. A balanced needle will be differently inclined, according to its distance from the two poles.

Over the north magnetic pole, it stands upright, with its north pole down. In 1831, Captain Ross came upon a spot in 70° 5′ N. lat., and 263° 14′ E. long., where the needle stood vertical. That spot must therefore be right over the north magnetic pole. Near the equator, again, there is no dip, and the needle lies horizontal. A line drawn through all such places of no dip is called the *magnetic equator*. It is an irregular line near to, but not identical with the earth's equator. Charts have been drawn up with lines showing all places where the dip is the same. To these the name of *isoclinic lines* and *charts* is given.

Like the declination, the dip is subject to *periodical* as well as *irregular* variations. At the beginning of the present century, the dip was 70° 35′ from the horizontal in London, and it has since then been gradually diminishing. In London, it is at the present time about 67° 50′, and there is an annual decrease of about 2·6′. It is found that the diurnal or daily variations, as well as the disturbances of magnetic storms, affect the inclination at the same time as they affect the declination needle.

15. *Magnetic Intensity.*—If a nicely poised needle be made to swing on a pivot or axis near a magnet, it will vibrate more quickly, or more slowly, according to the strength of the

magnet, and according to its distance from it. At the middle of the magnet, it will not vibrate so actively as at the ends; and the number of vibrations it will make in any time, say in one minute, will be an estimate of the *magnetic force* affecting it. Precisely in this way, then, is the strength or intensity of the earth's magnetism found at any place on its surface. At the equator, the needle, oscillating most slowly, shews the magnetic intensity to be weakest there. As we go north or south, it swings somewhat more quickly, indicating an increase of magnetic force.

16. *Magnetic Elements.*—These three indications, then, of the *declination*, as shewn by the compass needle, of the *inclination*, as shewn by the dipping needle, and of the *magnetic intensity*, as shewn by the vibrating needle, are termed the *magnetic elements* of a place. They are different at each place on the earth, and are always changing, so that each spot has its own magnetic history.

At the present day much importance is attached to these changes of the magnetic elements. An immense amount of labour has been spent in observing and registering the variations of the magnetism at different stations over the globe, and many important and unexpected facts have thus been elicited.

The variations that have been found to be regular in their occurrence, having periods either of a year, or of a month, or of a day, can evidently be traced to the influence of the sun or of the moon. These bodies are themselves, in all probability, magnetic like our earth, and they will act as huge magnets at a distance.

Some of the irregular variations can be traced, as we have said, to definite causes. But of the slow changes which take centuries to effect, no acceptable explanation has yet been given; and of the causes of other disturbances we know as yet absolutely nothing.

ELECTRICITY.

17. If we rub a piece of amber briskly with a dry cloth, it will attract a small feather or a bit of straw. The Greeks knew this as long ago as 600 B.C.; and yet in this little fact lay concealed for two thousand years the future of the now enormous science of Electricity. We owe the start, as well as the name, of the science to Dr Gilbert, a physician of Queen Elizabeth. He discovered, in 1600, that many other substances, such as sulphur and glass, act in the same way when rubbed. It was not the mere heating of the amber that was sufficient to account for this attraction. Dr Gilbert supposed that the rubbing produced a very subtile substance on the amber or glass, which somehow licked up the bits of straw or paper from a distance. He did not venture to speculate far on the nature of this strange substance; but he gave it the name of *Electricity*—from the Greek word *electron*, meaning *amber*.

For almost two hundred years, friction was the only known mode of producing the electrical state of bodies, till, in the beginning of the present century, the discovery of galvanism revealed another means. This was but the first of a series of extensions, and what was, at one time, the whole, forms now but a mere part of the science of Electricity.

The various sources of electricity, such as friction, chemical action, magnetism, and heat, naturally form the bases for the divisions of the subject. We shall accordingly begin with an account of the electricity of friction, which, if not of most practical importance, is no less interesting in itself than it is instructive.

FRICTIONAL ELECTRICITY.

18. *Elementary Facts.*—The first experiment in electricity is most readily shewn by means of a stick of common sealing-wax, a dry piece of cloth, and a few bits of paper. We have but to rub the sealing-wax once or twice to make it attract the bits of paper, just as a magnet does iron filings.

For experiments in this subject, it is useful to have a number of small pith-balls, formed from the pith of the elder-tree, or of the common sunflower. One of these, hung by a *silk* thread from a convenient support, is called an *electric pendulum*, and shews very readily the attraction of an electrified body.

But every substance which we rub as we did the sealing-wax will not behave in this manner. A rod of metal, held in the hand, will shew no trace of electricity, though it be rubbed ever so long. It is clear, therefore, that all bodies are not alike with regard to the electrical state.

The difference used to be explained by saying that amber, glass, and such substances are *electrics*, while the metals and others are *non-electrics*—that is to say, that the former class can be electrified by friction, while the latter cannot. This idea is now known to be erroneous. For, if the metal be held by a glass handle, and rubbed, it will at once shew its attractive power.

The true explanation lies here. In some substances, the electrical state is no sooner produced at any part than it instantly diffuses itself over the whole. In others, it is confined to the part where it is produced, or, at least, spreads over the rest of the body very slowly, and with great difficulty. According as bodies admit this instant diffusion or transmission of the electrical state or not, they are now termed *conductors* or *non-conductors*. *Non-conductors*, such as dry air, glass, shellac, etc., are also called *insulators*, because, if an electrified body is surrounded by such, its electricity is enclosed as in an island, and prevented from escaping over other conductors. The earth is a huge conductor, and any electricity, which we can artificially excite, must be carefully insulated from it, otherwise, if allowed to spread over the earth, it will be lost in its immensity, like a wave on a boundless sea.

We can now easily understand the difference between rubbing a rod of metal and one of glass held in the hand. In the former case, the electricity is dissipated as fast as it is produced, while the glass acts as the insulator of its own electricity.

But there is no such thing as a perfect conductor or a perfect insulator. In other words, the very best conductors offer *some* resistance to the diffusion of electricity, and the very worst do not wholly prevent it. Nor is there any sharp line between the two ; the difference is merely one of degree, and depends on a variety of causes, such as temperature. Thus, water is a moderate conductor, yet ice and dry steam are both insulators.

The following is a list of bodies in order, from the best conductors to the best insulators : *Silver*, *copper*, *gold*, *zinc*, *iron*, *lead*, *mercury*, *charcoal*, *acids*, *salt solutions*, *rarefied air*, *pure water*, *stone*, *dry ice*, *dry wood*, *porcelain*, *dry paper*, *wool*, *silk*, *glass*, *sealing-wax*, *sulphur*, *resin*, *gutta-percha*, *india-rubber*, *shellac*, *paraffin*, *ebonite*, *dry air*, and *gases*.

19. *Two Kinds of Electricity.*—Looking more closely at the action of a rubbed glass rod on the electric pendulum, we see that the attraction is merely momentary, and is followed by as brisk repulsion. Any attempt to bring the rod near to the pith, only serves to drive it farther away. But if an excited stick of sealing-wax be brought near, the pith instantly flies to its embrace, only, however, to be in a moment cast off, as it had been by the glass before. Banished from the wax, it will now find favour with the glass for an instant again ; and thus a continual exchange of sympathy for the one or the other electrified body may be kept up as long as the excitement continues.

Now, this curious behaviour of the pith can be accounted for only on the supposition that there are two opposite states of the electrical excitement, one peculiar to the glass, and the other to the sealing-wax. What the one repels, the other attracts, and the characters of the electricities must therefore be as opposite as are attraction and repulsion.

In any case, the excitement is either like that of glass or that of sealing-wax ; thus any electricity used to be defined as either *vitreous* or *resinous*. But these terms are not quite correct, as either kind may be got from the glass or from the wax, by varying the nature of the rubber. For *vitreous* and *resinous*, the terms *positive* and *negative* are now used—positive electricity being like that evoked on glass by rubbing with silk ; and negative, that evoked on sealing-wax by rubbing with flannel.

20. *Laws of Electricity.*—(1.) In order to produce the elec-

trical state, we must always have the contact of *dissimilar* bodies. We get no electricity by rubbing together two bodies precisely similar in nature and manufacture ; but a very slight difference is sufficient to render electrification possible. For instance, if we rub together two silk ribbons, of the same kind but differing merely in colour, we shall find one positively and the other negatively electrical.

(2.) We cannot produce one kind of electricity without an equal amount of the opposite kind at the same instant. Positive goes to one of the bodies, and negative to the other, according to some law which has not yet been detected. The kind of electricity that goes to each of the rubbing bodies, depends on some still hidden *relation* between the two bodies. Thus if we rub glass with silk, the glass assumes the positive state. But if we rub it with catskin, it assumes the negative. We know by experiment, though we cannot as yet tell the reason, that if we rub together any two substances in the following list, the one which comes first in the list will be positive : *Catskin, flannel, glass, cotton, silk, the hand, shellac, metals, sulphur, india-rubber, gutta-percha.*

(3.) Bodies similarly electrified repel, and bodies dissimilarly electrified attract each other. This corresponds to the law of magnetic action. If we take two piths hanging together by two silk strings, and touch both with an electrified body, such as a rubbed stick of sealing-wax, they repel each other and remain apart. But if we electrify one with positive and the other with negative electricity, they attract. Also if both are similarly electrified, but one more powerfully than the other, there will be an attraction between them, and a redistribution of their electricities.

(4.) The electrical excitement is only found on the *surface of a conductor*. This may be shewn by a hollow brass ball with an opening of an inch diameter or so, and fixed on a glass stand. However strongly we electrify the ball, not the slightest trace of electricity will be found inside. Faraday set a cylinder of wire-gauze on an insulating stand, and electrified it powerfully ; yet, strange as it may seem, none could pass by the meshes to the inside.

21. *Electrical Theories.*—Many theories as to the nature

of electricity have been proposed, but its real character is yet beyond our reach. The two most important historically, are the *fluid theories* of Franklin and of Symmers.

Franklin's theory is, that all bodies, when in the neutral state, contain a definite quantity of an extremely elastic, imponderable fluid which repels itself, but attracts matter. Bodies are positively electrified when they have more than their natural share of it, and negatively when they have less. Symmers' theory is, that bodies in the neutral state contain equal amounts of *two* electrical fluids, of opposite characters. By friction and other means, these can be separated, one going to each body rubbed. Each repels itself, but attracts the other, and one is peculiar to rubbed glass, and the other to rubbed sealing-wax. These fluid theories were long exclusively adopted, and on them are based all the leading terms of the science.

The modern tendency, however, is to depart from all *material* theories of electricity, and to adopt some one more or less analogous to those of heat and light. They tend to ascribe the electrical state to some modification of the ether which is believed to fill all space, and to pervade even the densest matter as easily as air does the branches of a tree.

Faraday and Grove ascribed all electrical phenomena to a polarisation of the molecules of bodies, or a *setting* of the molecules all in one direction, there being no such regularity when bodies are in the unelectrified state. Faraday, by a series of testing experiments, went far to establish this theory, which would overturn all the fluid theories.

22. *Induction.*—An electrified body has the power of inducing, or of affecting a neutral one at a distance in much the same way as a magnet does a piece of soft iron. This may be shewn very simply in the following way. A brass cylinder with rounded ends, and fixed on a glass support, has pairs of piths hung at each end (fig. 7). If, now, an insulated conductor, such as a brass ball, be charged positively, and brought *near* one end of the cylinder, *both* pairs of piths will instantly diverge, and as quickly collapse when it is taken away. It is easily shewn that the two ends of the cylinder are in opposite electrical states, and separated by a neutral

line of no electricity. Next the positive ball there is negative electricity induced. And so it is always. A charged body induces an opposite kind of electricity on the side of another next it, and the same kind on the farther side. If we had a series of cylinders like that in the figure, placed end to end in a line, without contact, we should find that the positive end of the first cylinder would act on the next just as the ball did on itself. Thus the induction might be transmitted through the whole of them; and, on our removing the inducing ball, they would all return to the neutral state instantly.

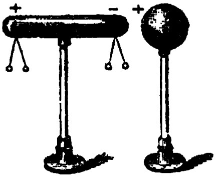

Fig. 7.

23. *All Electricity of a Polar or Dual Form.*—Opposite forces are here, as in a magnet, resident in opposite sides of the conductors. They are therefore said to be *polarised*, and, indeed, there seems every reason to believe that all electric action is of a polar nature. When a rubbed glass attracts a pith, it is an attraction between the positive of the glass and the negative it has induced on the face of the pith next it. This is quite analogous to the action of a magnet on a piece of soft iron. There is, however, an apparent contradiction of this polar doctrine, for we may give to a body by induction only *one* kind of electricity, and this it retains permanently. If, while the cylinder is near the positively charged ball, we touch it for a moment with the finger, we uninsulate it, and allow its electricity to spread over the earth and become lost. Only the positive, however, will escape; the negative will be held *bound* to the positive inducing charge. If *after* thus touching the cylinder, we remove the ball, we shall have remaining on the cylinder *only negative* electricity. This is very different from what we can do with magnetism. There seems here no second electric polarity.

The explanation, however, is not far to seek. All matter can be excited electrically, but only one kind magnetically. In the case of electric polarity, then, it is possible to transfer one of the poles by induction to surrounding objects, whereas, in magnetism, this transference cannot take place. Not only is it possible, but it is what must take place before we can have any electricity at all. Faraday has shewn that a body cannot be electrified at all, either positively or negatively, unless there be surrounding objects to which it can transfer the opposite electricity by induction, and that the degree of charge which it can take is just in proportion to this facility for induction.

When a body is charged by induction, then, we see its electricity is opposite to that of the charging body. But when we charge it by contact or by spark, the electricity is of the same name as that of the charging body. Yet the latter is due to induction as well as the former. For when we bring the ball (fig. 7) near the cylinder, the positive electricity of the ball tends to unite with the negative it induces next it. The tendency increases as they approach, till at last it is sufficient to burst through the interval of air; and the two flash together with a spark, and neutralise each other. Thus, the positive electricity at the other end of the cylinder is left alone without its negative, just as if the positive of the ball had passed or flowed over to it.

Faraday shewed that the air is the medium by which the electric force passes between an inducing and an induced body. He found that, if he changed this medium and put shellac for air, the amount of electricity induced was about twice as much as with air. Hence he called shellac a better *dielectric*, or medium of induction, than air. Bodies, he would say, differ merely in the facility with which their molecules communicate the electric state. If induction, then, be an action at a distance, it is at no greater distance than between the molecules of bodies.

24. *Distribution of Electricity.*—Whatever may be the nature of electric force, it may be assumed as self-evident that its intensity, or tension at any part of the surface of a body, will be less in proportion as the surface is increased. If two insulated balls, one electrified and the other neutral, be made to touch, the charge will be just divided between them in proportion to their size. The intensity of the excitement has nothing to do with its quantity; and the same quantity may, in different circumstances, possess very different intensities.

Not only does the size, but even the *shape* of a body very materially influences the intensity of the excitement at different parts of its surface. A ball, since every part is alike, will have the same intensity all over its surface. But an electrified cylinder will have the greatest intensities at its ends. With a body such as that in fig. 8, the tension will be far greater at the ends than at the middle. In general, the farther a body is from the spherical shape, the farther will its intensity be from uniform distribution. When the body ends with a sharp point, the electricity seems all to accumulate at the point, so that it is too great to be retained on the body, and it bursts from it instantly.

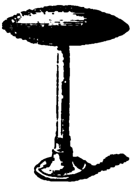

Fig. 8.

ELECTRIC MACHINES.

25. In the glass tube and silk rubber we have the embryo of an electric machine; the principle of the large machine is quite the same, and its object is merely to produce electricity more readily and copiously than the small tube does. It is not necessary to construct a grand or expensive machine to try most of the experiments given here. The first electrical machine of the famous Faraday was made by himself from a common glass bottle.

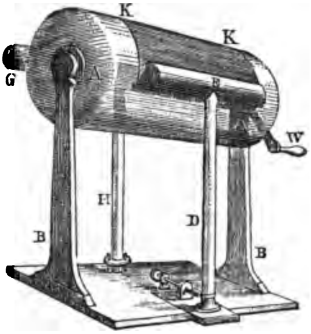

Fig. 9.

26. *Cylinder Machine.*—Fig. 9 represents one of this class of machines in its very simplest form. It consists of a strong glass cylinder, A, which can be turned by a handle. Against one side of it presses the rubber, E, which is a cushion of leather stuffed with horse-hair, and having its pressure regulated by means of screws. Facing the opposite side is a row of brass points, near to yet not touching the glass.

These metal points communicate with a brass cylinder, G (rounded at the ends, and mounted on well insulating glass supports), which is called the *prime conductor*.

When the handle is turned, the friction of the rubber excites positive electricity on the glass, and negative on the rubber itself. Being a non-conductor, the glass retains its electricity till brought opposite the points, when it is discharged or picked up, as it were, by the action of these. To prevent dissipation of the electricity from the glass as it rushes through the air, a flap of silk lies over the cylinder from the rubber to near the metal points. In this way, then, positive electricity collects on the prime conductor, and negative on the rubber. If the latter were insulated as well as the former, the tendency of the electricities to unite at the rubber would increase with its charge, and a limit to the power of friction to prevent this would very soon be reached. By connecting the rubber with the ground, we get rid of the negative electricity, and can thus go on accumulating to a much greater degree the positive. In many instruments, the rubber is connected with an insulated cylinder similar to that of the prime conductor. Positive or negative electricity may then be had at pleasure, by connecting with a metal rod or chain either the rubber or the prime conductor with the ground. But except for this choice which it puts in our power, it is not necessary to insulate the rubber at all.

27. *Plate Machine.*—One of the best existing forms of plate machines is that shewn in the figure, and known as Winter's machine (fig. 10). A round disc of stout plate-glass or vulcanite forms the excitable surface. It is completely insulated by the glass support *e*, and the glass axle *a*, which turns it. The chief advantage of the plate arrangement is that both sides can be rubbed at once. In this machine, the rubbers are triangular-shaped pieces of wood, with a padding of one or two layers of flannel covered with leather; and a large flat rubbing surface thus acts on the plate.

From these rubbers a flap of oiled silk passes on each side of the plate to near the collecting points, to prevent loss of electricity. The attraction of the rubbed plate keeps these flaps in position when the machine is in action; at other times a split pin, *g*, is used to keep them up.

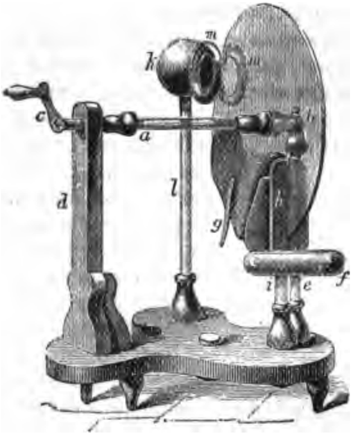

Fig. 10.

A peculiar feature in Winter's plate machine is a large ring which fits into the ball of the prime conductor. It is apparently a wooden ring, but the core consists of a metallic wire, which communicates with the prime conductor, when it is fitted in its place. The figure (fig. 11) shews a section of the ball of the prime conductor with the ring so fitted on. It serves to increase the accumulation of electricity enormously; the wooden envelope appears to prevent the discharge into the air, as the silk flap does with the electricity of the plate.

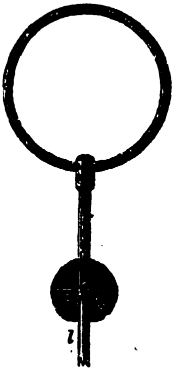

Fig. 11.

But we must not omit to notice that the frictional excitation of electricity is, in all these machines, very greatly enhanced by covering the surface of the rubber with an *amalgam*, or metallic compound. It is in the shape of a fine powder, and is usually made of mercury, zinc, and tin ; it is spread on with a knife, and made to adhere by the aid of a little grease.

28. *The Electrophorus.*—This is the least expensive of all electric machines, and forms a useful piece of apparatus when we do not require electricity in great quantity.

It usually consists of a tin mould filled with shellac, and a movable tin cover with an insulating glass handle, as seen in fig. 12. The shellac is generally mixed with wax, to make it less brittle ; but any resinous cake will do, if it be even and smooth on the surface. A round disc of vulcanite forms an excellent substitute for the shellac.

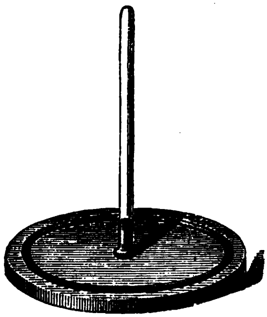

Fig. 12.

The principle of action of the electrophorus depends on induction, and is easily understood. If the cake be excited, say negatively, by striking with a catskin, it will not give up its electricity readily, because it is a bad conductor. Now, this negative electricity will induce positive on the adjacent sides of all objects round the cake. But as shellac is a splendid dielectric or medium of induction, the power will almost all act through it, and so keep positive electricity ***bound*** on the face of the mould next the cake, the negative being diffused over the earth. If, now, we put on the cover, the electricity, loath to leave the cake, will act on it by ***induction***, rather than pass to it by ***conduction***, and by induction powerfully, because the cover is so near. So, then, if we touch the cover for an instant, the negative induced on its upper side escapes ; but the positive is kept bound by the cake, till we lift the lid by its handle, when a sharp spark passes to the knuckle held near it. By putting on the cover, touching, and then lifting it, we may get any number of sparks from the cake. Once excited, it will keep its power for a long time, sometimes for weeks or even months together. The mould shields it by induction, as the armature of a magnet does its magnetic charge.

Within the last few years several machines have been invented, all partaking more or less of this inductive principle of the electrophorus. The most important are those devised by Holtz of Berlin, Toepler of Riga, Mr Varley, and Sir W. Thomson. We have space here only for a short account of the most popular of these, viz., that invented by the first named electrician.

29. *Holtz's Induction Machine.*—Fig. 13 shews the machine invented by Holtz in 1865. It requires a little electricity as capital to start with, and this is speedily accumulated on the compound interest principle till it is sufficient to give powerful sparks or shocks, to charge a Leyden jar, and to exhibit all the ordinary effects.

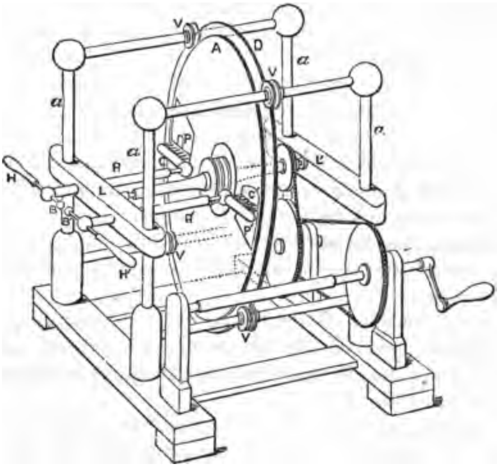

Fig. 13.

It consists of two thin discs of glass, of about 20 inches diameter, one of which, DD′, is fixed; the other, AA′, movable. They are placed very near together. A rapid rotation can be given to the movable plate by means of the multiplying wheels E and E′.

In the fixed plate, DD′, are seen three large holes, a round one in the middle for the clear passage of the axle, and the other two, FF′, of a sort of oval form, at the ends of a horizontal diameter.

On the upper side of one window, and lower side of the other, are glued two pieces of paper, PP′, with pointed tongues projecting into the openings.

Two rows of metallic points or combs, CC′, opposite the windows, collect the electricities from the movable plate which rotates between them and the fixed disc.

Communicating with these combs are two knobs, BB′, which form the poles of the machine, and between which the discharges take place.

In order that the machine may work, we must have a very dry state of the atmosphere, and the insulators clean and dry. The knobs must also be pushed in contact at starting.

Then, having electrified a small piece of vulcanite by friction, we hold it against one of the paper tongues, while we turn the handle quickly for a few seconds.

If the machine be working, we hear a crackling noise, and see a torrent of sparks between the knobs whenever we separate them.

By simply turning the handle we can generate any quantity of electricity; and, if the insulation be good, we may not need to renew the charge of the paper tongues (or armatures) for hours on end.

In all such machines the obvious advantage is that much less of the energy is wasted in the production of mere heat than is the case with the ordinary rubbing machines.

EXPERIMENTS WITH THE ELECTRIC MACHINE.

30. The phenomena of *electric attraction* and *repulsion* may be illustrated in hundreds of ways. If a common glass tumbler be electrified inside by a number of sparks from the machine, and then inverted over a few piths on a table, the piths will dance up and down within the tumbler in an amusing manner. They are gradually discharging the electricity of the tumbler, and the dance may be kept up for hours.

Small pith figures will dance between two metal plates, the lower of which is uninsulated, and the upper in connection with the prime conductor.

The repulsion of similarly electrified particles is shewn very nicely by the *electric water-pail*. This is simply a small tin pail with fine holes pierced in the bottom. If filled with water, it will, when held in the hand, trickle out in drops merely; but if hung on the prime conductor, the water particles becoming electrified mutually repel, and issue in a multitude of fine jets. The *electric wind* is a somewhat similar result of the electrification of the particles of the air. If a pointed rod be stuck in the prime conductor, and the machine worked, the hand placed before the point will feel a sort of wind. The experiment may be made pleasing to the eye, by making the wind drive small models of mills or a small paper orrery.

This action of *points* is very curious. So long as the electricity escapes from the prime conductor by a point, no spark can be drawn from it. Nor, on the other hand, can any spark be got, if a pointed conductor be held at a distance of a few feet from the machine. This is because the electricity escapes silently in each case, and cannot acquire a tension sufficient to give the spark. The snap, heard when a spark is drawn, is due to the disruption or scattering of the air particles, caused when the positive electricity of the machine combines with the negative it induces on the hand or the object brought near it.

31. The *heating effects* of electricity are also very powerful. If a spark be drawn from the prime conductor by an iron spoon containing a little ether or alcohol, the liquid will instantly inflame. A single spark will also light a candle newly blown out, or a gas-jet issuing from a metal burner.

32. The *luminous effects* of electricity are, of course, most visible in the dark. The light of the spark is intense when the machine is powerful and in good order. When short, it seems straight; but it gets more irregular and zigzag like forked-lightning when it is long. If the ball of a Winter's machine be allowed to discharge into the air, the spark will be seen to spread out into the form of a *brush*. But if it be

made to discharge silently from a point, the point will be seen in the dark, crowned with a tuft of light, which is usually called the *glow*. The electric spark becomes much more extended in rarefied air. A tall glass jar, from which the air can be pumped out, is used to shew this. It has a brass ball at each end, and the electric spark passes between these by putting one end in connection with the machine, and the other with the ground. The glow throughout the jar has the appearance of a column of mauve-coloured flame. But the colour of the luminous discharge varies with the nature of the metals between which it passes, and also with the nature of the gaseous medium. The flickering light thus produced has a striking resemblance to the Aurora Borealis.

ELECTROSCOPES AND ELECTROMETERS.

33. Instruments for *detecting* the presence of feeble electricity are called *electroscopes;* and those for *measuring* the degree of excitement present in any body are termed *electrometers*. Both are indispensable in electrical inquiries.

34. The simplest form of electroscope is the electric pendulum already mentioned.

Far more delicate, however, is what is known as the *gold-leaf electroscope*. A good form of this is shewn in fig. 14. Two strips of gold-leaf about half-an-inch broad are fixed to a brass rod, so as to hang inside a glass globe of about four inches diameter. The brass rod ends externally in a ball, and is insulated with sealing-wax from the brass fitting of the neck. Before the rod and leaves are finally fixed, the interior of the globe is thoroughly dried, that the insulation of the leaves may be as perfect as possible. When so finished, this forms a very sensitive instrument: an extremely small amount of electricity being sufficient to make the leaves diverge. A strong charge would be very apt to tear the gold-leaves, and it must therefore be used with care.

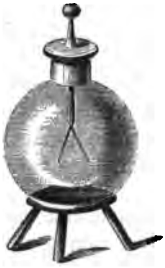

Fig. 14.

When we wish to test the kind of electricity on a body, we simply bring the electroscope near the electrified body, and touch its knob for an instant. By withdrawing the electrified body, we leave the leaves charged oppositely to itself, and so they diverge. To find if they are positively or negatively charged, we rub a glass rod and bring it *near* the knob : if *positively*, the leaves will diverge still more under the induction of the glass; but if *negatively*, they will collapse by the negative being attracted to the positive of the glass rod.

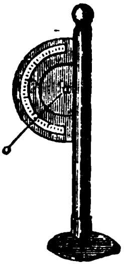

Fig. 15.

35. Of electrometers, one of the first and simplest is that shewn in fig. 15, and called the *quadrant pith electrometer.* It consists of a conducting-rod of brass or of box-wood, with a divided semicircle of cardboard attached. A straw ending in a pithball moves about a pivot at the centre of the semicircle, and indicates, by the extent of divergence from the brass rod, the degree of electrification of the instrument. It is very far from delicate, however, and gives but a rough test of electric tension. Its chief use is to put on the prime conductor of a machine, to give an idea of its condition.

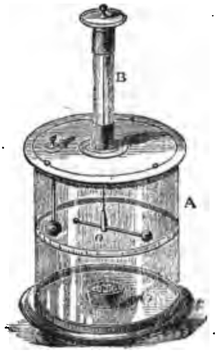

Fig. 16.

36. *Coulomb's Torsion Electrometer* is a much more delicate instrument of this class, and one which has had a considerable effect in rendering electricity an accurate science. It is represented in the figure, and merits a short description here (fig. 16). A light rod of shellac, carrying a small disc of gilt paper at one end, is suspended by a silk fibre, or fine silver wire, within a glass cylinder, A, and a glass tube, B, surmounting it. The cylinder is divided into degrees by a graduated strip of paper pasted round it; and the position of the gilt disc is known by reference to this graduation. Through an opening in the lid of the cylinder, a brass ball, at the end

of a shellac rod, can be passed so as to be supported on a level with the gilt disc.

Before using the instrument, we must adjust it so that, when the fibre hangs free from twist, the gilt disc just touches the ball. If this ball be electrified, it electrifies, and then repels the disc, to a distance depending on the strength of charge in the ball.

Now, the principle on which its use depends is that—*the force required to keep a fine wire or fibre twisted through any number of turns and parts of a turn, is just proportional to that number of turns and parts of a turn.* By turning the button, to which the fibre is fixed at the top of the tube, we can bring the disc to any distance from the ball that we please, say to 30°, as read off on the cylinder. Then the number of turns and parts of a turn (read off by reference to a graduated ring on the top of the *tube*), added to the 30° between the ball and the disc, gives the whole amount of twist of the fibre from the first position of no twist. This force of twist is just balanced by the repulsion of the electricities in the ball and disc, and is therefore a measure of that repulsion.

37. *Laws of Electric Action.*—By a great number of such experiments, Coulomb established the following laws of electrical attraction and repulsion:

(1.) The force of attraction or repulsion between unlike or like electricities *decreases* as the distance between them increases, and decreases at the *square* of the rate of increase of the distance. Thus the force of repulsion between two similarly electrified piths, 1 inch apart, would be reduced to $\frac{1}{4}$ of that at 2 inches', and to $\frac{1}{9}$ at 3 inches' distance.

(2.) This force depends also on the *product of the intensities* of the electricities that are acting on each other. So that if one ball had its electricity raised to three times its first amount, and another to twice, the resulting action between them would be six times as strong as at first.

38. The construction of delicate electrometers has of late years occupied the attention of our greatest authorities on this subject. Their aim has been to render electricity a strictly accurate and mathematical science; and the labours of Sir

William Thomson and others have done more to effect this than any have ever done before. Sir W. Thomson has himself invented several forms of electrometers from time to time, each more accurate than the former; and now his *Quadrant Aluminium Electrometer* is out of sight the most delicate instrument of the kind. A description of these may be found in the British Association Report for 1867, or in Professor Jenkin's recent text-book "Electricity and Magnetism."

CONDENSED ELECTRICITY.

39. There is a limit to the accumulation of electricity on any surface. After it has reached a certain degree of intensity or tension, it discharges into the air as fast as it is produced. But if we bring another conducting surface *near to* the charged one, the latter may be much more highly electrified than before. This is the principle on which the *Leyden jar* depends, and a description of it will serve to explain the nature of condensed or accumulated electricity.

40. *Leyden Jar.*—This is simply a wide-mouthed glass bottle with two coatings of tinfoil, pasted one outside, and the other inside (fig. 17). The coatings reach only about four-fifths of the height of the jar, and the bottom is also covered inside and outside. A brass rod ending in a knob passes through a wooden plug in the mouth of the jar, and communicates with the inside coating by a piece of chain. If, now, we set such a jar on an insulated support, so that sparks can pass from the prime conductor of a machine to its knob, a few sparks will pass, and then it seems charged, and will take no more. But if we hold a knuckle near the *outer* coating, sparks will again pass freely to the knob; and for every spark to the knob, a similar one passes to the knuckle from the outer coating. This continues for some time, till again the jar becomes fully charged or saturated. So long as it remains on the insulated support, we may touch *either* the outside coating *or* the knob. But

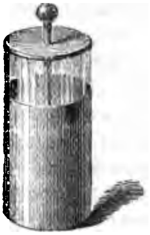

Fig. 17.

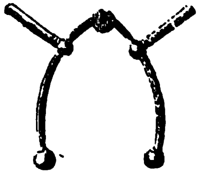

Fig. 18.

if one hand touch the outside, and the other be brought near the knob, a bright spark passes to it, and a very violent shock is experienced. If the same thing be done again, a feebler spark and shock ensue, and then the jar is quite discharged. This experiment had better be made, however, with a pair of discharging tongs (fig. 18), as it is neither pleasant nor safe to do it with the body. They are simply two brass arms ending in balls, and movable about a hinge by means of glass handles. One ball is made to touch the outer coating, while the other is brought near the knob. The usual way of charging the jar is to hold it in the hand, and present its knob to the prime conductor of a machine.

41. *Theory of the Jar.*—Its theoretical explanation is just a case of the general principle, that the charge which a body can receive is greater in proportion to its facility for induction. Now, when the inner coating is positively charged from the machine, it acts by induction on all neighbouring matter, and the nearer and larger this matter is, the greater will be the charge it can take. If, then, the jar be uninsulated, we have really the surface of the earth brought within the thickness of the glass from the inside coating. The glass, too, which intervenes is a very good dielectric, much better than air; at the same time its tenacity can resist the strain of a far higher polarisation of its particles than air would do. Thus we have every facility for a high charge of the interior. It would, of course, be greater, the thinner the glass; but thin glass is easily ruptured, and would be of no use. If we could have a jar of indefinite thinness, and yet of great strength, the charge which it could take would be unlimited. As this is not the case, other bodies round about compete, for induction, with the outer coating. Ultimately, the facility of induction through the air on these becomes greater, and there is a limit to the charge.

If the inside is positively charged, the outer coating is negatively next it, and the two are bound together by the action of the glass, which is such a good dielectric. The glass indeed seems to be the chief seat of the charge, and the coatings seem to serve merely to distribute it over the non-conducting glass. This is usually illustrated by having a jar with movable coatings. After it is charged, we may remove each coating, handle them, put them back in their place, and get almost as strong a discharge as ever. The *secondary* discharge, which is got by connecting the coatings after the first discharge, is ascribed to the same cause. The glass does not give up all its charge at once, and sometimes three or four subsequent discharges may be got.

42. *Leyden Jar Battery.*—For great power, large surfaces are necessary. A large jar would give this, but it is preferable to use several moderate-sized ones, and unite them to form what is called an electric battery. The jars are placed on an insulated stool covered with tinfoil, and their outer coatings are thus in communication. All the knobs are connected by metal rods, and so all the inner coatings act as one. If, after charging, we connect any knob with an outer coating, the whole battery will be discharged, and with a force which, for the same degree of charge in a single jar, will be proportional to the number of jars employed.

43. *Power of Accumulated Electricity.*—The effects of condensed electricity are very powerful. If the spark be passed through a bad conductor, such as shellac, resin, or glass, it may be shivered into powder. A fine wire of metal will be made red-hot, or even melted, by the discharge of a good battery. The physiological effects also are tremendous. A single jar, of moderate size, is sufficient to give a shock to a whole regiment. The men have simply to join hands and form a ring, the first man holding a jar, and the last man touching its knob. All will feel the shock at the same instant, so rapid is the rate of discharge. Indeed, the velocity of electricity, or rather of the electric discharge, is almost incredible. Wheatstone, by a very ingenious method, has calculated that it can be no less than 288,000 miles a second—that is, it might flash round our earth in one-tenth of a second. More recent experiments and calculations, however, bring the velocity nearer to that of light, which is about 190,000 miles a second.

ATMOSPHERIC ELECTRICITY.

44. *Ordinary Electricity of the Atmosphere.*—It is commonly said, when one sees a sultry cloudy sky, that the air is electrified; yet in all kinds of weather, clear as well as cloudy, it is more or less electrical. The cause of this is not very well known, but it is usually ascribed to evaporation. Each little particle of moisture is borne aloft with its little charge of electricity begotten by the electrical earth, till the multitude of little drops that forms a cloud is more or less electrified as a whole.

A clear sky is always *positively* electrical, and most strongly so soon after sunrise and again soon after sunset. It is least when the heat of the day is greatest, and also just before sunrise.

In cloudy weather, it is sometimes positively, sometimes negatively electrical: and rain, snow, hail, etc., when caught on an electroscope, are found sometimes positive, sometimes negative.

45. *Thunderstorms.*—In summer the usual result of a few days' strong heat and copious evaporation is to produce vast masses of cloud highly charged with electricity. These are positive or negative, according to the state of the globe where they have been formed. When two oppositely charged clouds are borne by the wind within attracting distance of each other, they rush together, and their electricities combine with terrific vividness; and this is the extraordinary development of atmospheric electricity that we call a thunderstorm. If the cloud is oppositely electrified to the part of the earth underneath it, and if it descend sufficiently low, the discharge takes place between the cloud and the earth, and the storm is then most dangerous and awful.

46. *Lightning.*—Franklin was the first to identify the lightning flash with the electric spark, by his famous kite experiment. The same disruptive, burning, and luminous effects are common to both, though in vastly different degrees. There are several kinds of flashes.

First, there is the *forked-lightning*, or zigzag line of bright light which may be seen darting between clouds, or from the clouds to the earth. Often it splits up, as it approaches the earth, into branches several thousand feet apart. Its zigzag form is owing to the resistance of the air.

Second, there is the large indefinite blaze of *sheet-lightning*, ascribed to an electric discharge within the clouds themselves, which illuminates their mass for a moment. When it occurs at a great height or distance, no thunder is heard, and a vague flash passes across our field of view. Such is common in summer evenings.

A third and less frequent form is that of *ball-lightning*, which is perhaps rather a meteor than an electric phenomenon. It is said to occur in this way. After a violent explosion of lightning, a ball is seen bounding like a bomb to the earth. When it reaches the ground, it either splits up at once and disappears, or it rebounds like an elastic ball before doing so. It may last as long as ten seconds, and is thus very different from the flash, which has been proved to last less than one ten-thousandth of a second. It is very dangerous, and readily sets fire to any building in its way.

47. *Thunder.*—The snap of the electric spark is heard on a grand scale in the thunder-clap, which accompanies the lightning. Whether it is due to the disruptive scattering of the air particles in the line of discharge, or to the rushing in of air to fill up the vacuum produced, is not quite clear. Nor can the prolonged rolling, the strange rising and falling of the peal, be properly accounted for. When the thunder is near, it is short and sharp, though the same report may have been heard as a long roll at a distance. The echoes sent between the clouds and the earth may account for this rising and falling to some extent, but not fully. Some assign the cause to the zigzag path of the flash, forming a series of centres of sound, not all in a line. The waves of sound may alternately swell into one roar, or meet and weaken each other. Thunder is not so loud as we are apt to fancy it. It has never been heard more than 14 miles from the flash. The cannonading at Waterloo was heard at Creil, in the north of France, about 115 miles from the field.

48. *Lightning-conductors.*—Electricity, like any other force, always takes the easiest route. We have seen that, if we

hold a pointed rod of metal to the prime conductor of a machine, its electricity will be all drawn silently off to the ground, as fast as it is produced. In the same way, if we present a pointed rod near to a charged cloud, its electricity will pass silently and harmlessly to the earth. This is the principle of the lightning-conductor. It is a pointed rod of copper or galvanised iron, reaching from 8 to 30 feet above a building, and carried down to the earth, in which it is carefully buried. The part above the building is called the *rod*, and the rest the *conductor*. They must be very carefully constructed, otherwise their presence is the opposite of protective. It is led down two feet or so into the ground, and then turned away into a well or water, if possible, or else into a drain filled with charcoal for 12 or 16 feet. In large buildings, there are several rods all connected to one common conductor. In ships, there is one on each mast, leading to the metal of the keel. When properly made, they are, beyond all doubt, sufficient protection from the ravages of lightning.

GALVANISM.

49. The discovery of galvanism in the end of last century was the beginning of a new era in the history of electrical science. No results of great practical value had followed the study of the electricity of friction. Its nature was so capricious. A constant tendency to escape made it difficult to excite, and yet more difficult to control; and it found a place merely in the laboratory of the philosopher, or among the curiosities of the drawing-room. But the revelation of another and an easier mode of producing the excitement soon drew the attention of the whole scientific world. This new field of investigation displayed an entirely novel class of phenomena; and the short period of half a century saw marvellous and unexpected results. Frictional electricitity thus became of subordinate importance, while galvanism or voltaic electricity became of the highest practical interest.

50. *Elementary Facts.*—Galvani, an Italian professor of anatomy, discovered, about the year 1780, that the limbs of recently skinned frogs were convulsed, if near an electric machine, whenever he drew sparks from the prime conductor. Experimenting on this electric susceptibility of frogs, he accidentally noticed one day a similar convulsion from a totally different cause. This was when a copper hook, stuck through the spine of a frog, came in contact with a piece of iron which was touching the muscles of the leg. The same action, though less energetic, took place when he connected the nerves of the back with the muscles of the leg by a single metallic conductor. Galvani identified the effect with that produced by the electric machine; and, after a great number of experiments, he ultimately ascribed it to the flow of a vital electric fluid from the nerves to the muscles. One fluid he considered peculiar to the muscles, and the other to the nerves.

Volta, an Italian professor of natural philosophy, repeated these experiments but came to a different conclusion. As the action was much more violent when *two* metallic conductors were used, he inferred that the mere *contact of the different metals* was the exciting cause of the electric flow. One of the metals assumed the positive, and the other the negative electricity, and the frog's limbs but served as a sensitive connector. Such was the voltaic view.

51. *Volta's Pile.*—In support of his theory, Volta devised many ingenious experiments, and among others was a simple apparatus, which excited extraordinary interest in its day. It is called Volta's pile, and was invented by him to shew the effect of a combination of metallic contacts. It consists of a number of pairs of round discs of copper and zinc piled together, as shewn in fig. 19. The copper and zinc of each pair were soldered together, and the zincs all faced the same way in the pile. Moist discs of cloth were put between each pair, merely, as Volta held, to prevent direct contact between the pairs, and yet be a sufficient conductor. The pile is insulated, and, as afterwards modified, ends in a copper plate above and a zinc plate below. By this means, a powerful accumulation of positive electricity was found

at the copper plate, and of negative at the zinc. When the two ends of the pile were connected by a wire, a strong and steady flow of electricity set in from the one side to the other. On the limbs of a frog, the effect was much more violent than that of a single pair of metallic conductors. So then, argued Volta, the mere contact of the copper and the zinc produces opposite electricities in each; for the more we multiply the contacts, the greater is the electrical power of the pile.

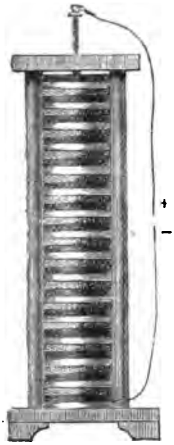

Fig. 19.

Volta's theory took little account of the moisture of the cloth, but its importance was not to be overlooked. It was observed that, after a time, the zinc plates got corroded by the action of the moisture; and, if the cloths were wetted with salt water, a stronger electric action resulted, as well as a faster corrosion of the zincs.

Suspicion fell on this very *corrosion* as the real active agent in the matter. The doctrine of Volta was challenged by several eminent philosophers; and a theory tracing the flow of electricity to chemical action was set up against it. By the genius and labours of such men as Davy, De la Rive, Becquerel, and Faraday, a vast array of evidence has been brought to bear in favour of the chemical theory.

But, after much wrangling over this point, it now appears that both sides were so far in the right. Mere contact of dissimilar metals does seem to produce a difference of electric *condition* in the two, though it cannot in itself be a source of *power*. For this chemical action is absolutely necessary. So that before we can have a galvanic *current* we must have both metallic difference and chemical action.

52. *General Idea of Galvanic Action.*—If a plate of copper, C (fig. 20), and a plate of pure zinc, Z, are put into a vessel of water, mixed with a little sulphuric acid, and they be kept from touching, nothing is seen, and no chemical action goes on.

But the moment they touch at any part, either within or out of the liquid, bubbles of gas appear at the copper plate, and they continue to form till we separate them again. We have the same result if we connect the plates, not directly, but by wires fastened to the plates. All that is visible is the production of the gas bubbles; but a hidden and most curious electric action is going on along the wire, and indeed, through the whole arrangement. For if we bring the connecting wire near a magnetic needle, the latter instantly recognises its presence and turns aside from its north and south position. Or if we break the wire and put the two ends on the tongue, we perceive a saltish taste, which continues until we lift one of the plates out of the acid water.

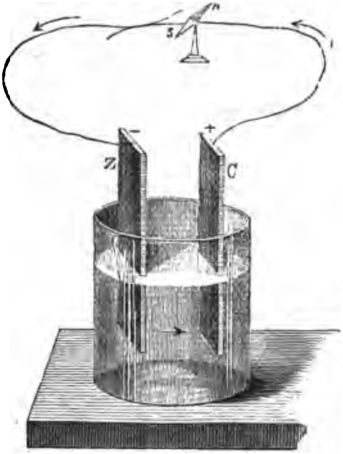

Fig. 20.

On breaking the connecting wire, we may find by a delicate electroscope that the two ends have feeble charges of opposite electricities, the wire leading from the copper having positive. There the electricities remain shut up, and the chemical action suspended, till we bring the ends together. Then the opposite electricities combine and neutralise each other; and the whole, plates and wires, become discharged or reduced to electric rest. But only for the instant; the action of the acid water sends a fresh supply of opposite electricities to each plate. So there is an incessant production and combination of the two electricities.

This constant succession of electric discharges is called a *current*, and it is said to *flow* in a *circuit* through the liquid, plates, and wire. If the circuit be *anywhere* broken, as by cutting the wire or lifting one plate out of the liquid, the *flow* of electricity instantly ceases. But the ends of the circuit, where the break is, become charged with opposite electricities; and the excitement is then said to pass from the *dynamic*, or motive state, to the *static*, or reposing state.

53. *Theory of Action of a Galvanic Couple.*—On collecting some of the gas, which is seen to form at the copper plate, we find it to be hydrogen. Why it should appear there, and not at the zinc, we shall now explain. When the plates of a galvanic pair are put in acidulated water, they instantly assume opposite electrical states, the zinc taking the positive, and the copper the negative state. Between these two plates we have also, in the molecules of the liquid, a series of movable heterogeneous couples; for each molecule of water consists of a hydrogen molecule bound by chemical attraction to an oxygen one. Now zinc and copper have each an affinity for oxygen, but zinc far more than copper. When a plate of each is put into acid water, then, we have this result along each line of molecules. The zinc plate turns the oxygen end of the first molecule to itself, and weakens its attraction for its hydrogen fellow. The latter turns its spare strength to attract the oxygen of the next molecule, and so on, till ultimately the positive hydrogen is presented to the copper, for which it has no liking. In this way, then, we see the action of the acid water on the zinc, or the chemical affinity between the two, is a force urging all the particles of the liquid to set in a certain direction. In like manner, the chemical affinity of the copper for the oxygen tends to set the particles all in an opposite direction.

The difference between these two forces constitutes what is called the *electro-motive force* of the couple. Had we taken a plate of silver with the plate of zinc, the resulting electro-motive force would have been still greater, because silver has less affinity for oxygen than copper has. But had we taken two plates of zinc, or two of copper, we should have been setting two equal forces against each other, and the electro-motive force would be *nil*. As a general rule, *the electro-motive force is greater the greater the difference of the metals in their liability to be acted on by the liquid.*

The face of the zinc, then, has positive, and the face of the copper negative electricity; and the farther ends of each wire attached to the plates will have an opposite electricity to that on their faces. That is to say, the end of the wire from the copper will have positive, and the end of the wire from the zinc negative electricity.

When, now, we bring the ends of the two wires together, the positive electricity in the end of the copper wire tends to unite with the negative at the end of the zinc wire. Yet so feeble is the degree of polarity, or so weak is the *tension* of each electricity, that they are unable to unite unless there be absolute contact. When there is this, the two combine, and an instantaneous electric discharge is set up along the whole polarised course. The zinc can now unite with the oxygen molecule next it; the hydrogen molecule set free unites with the oxygen of the next molecule to re-form water; and so the hydrogen and oxygen molecules pair off, till next the face of the copper is left an unmatched one of hydrogen. Having no affinity for copper, the hydrogen escapes in its natural form of gas. There is thus, with such a galvanic couple, an incessant union of oxygen with the zinc plate to form zinc oxide, and a setting free of hydrogen at the copper.

For the sake of simplicity, we have here supposed the liquid to be pure water. But this would only give a very feeble current, for the oxide of zinc, being a bad conductor, would stick to the surface of the plate and stop the action. A little sulphuric acid added to the water serves to dissolve this zinc oxide, and keep the surface of the plate clean and ready for action. Theoretically, the action is the same as before. The liquid may be regarded as composed of two molecules, one of hydrogen, and one of *sulphion*, formed by the union of the sulphuric acid with the oxygen of the water. This sulphion molecule behaves exactly as the oxygen did: it unites with the zinc to form sulphate of zinc, and hydrogen escapes at the copper plate.

54. *Electro-chemical Order of the Elements.*—We have just seen that zinc takes positive, and copper negative electricity, when they form a galvanic pair, simply because zinc is the more oxidisable of the two. If we form a pair with copper and gold plates, we find the copper plate is now the positive

one, and the gold the negative, because gold is even less oxidisable than copper. The plate which is more oxidisable, or more readily acted on by the liquid, always becomes positive, and is therefore said to be electro-positive to any less oxidisable metal. Knowing the relative degree of oxidability of any two metals, we can at once tell how they would act as a galvanic pair. The direction of the current is *defined* as being from the positive plate to the negative within the liquid, and from the negative to the positive without. Therefore, we have a general rule that, if we form a galvanic couple with any two metals and a dilute acid, the current will flow *outside* the liquid, or in the communicating wire, *from the metal which is least acted on by the acid to the other.*

In the following list, the more common elements are arranged in order of their oxidability, or in electro-chemical order: *Potassium*, *sodium*, *manganese*, *zinc*, *iron*, *lead*, *tin*, *bismuth*, *copper*, *silver*, *mercury*, *platinum*, *gold*, *hydrogen*, *carbon*, *phosphorus*, *chlorine*, *nitrogen*, *sulphur*, *oxygen*.

From this we know at once that a zinc-carbon pair will give a current flowing, *within* the liquid, *from zinc to carbon.* It follows, from what has been said, that the electromotive power of any combination will be greater the farther apart they are in this list. For example, a zinc-platinum pair will be more powerful than a zinc-copper one.

But this is the electro-chemical order only for dilute acids as the exciting liquid. With other liquids, we may reverse the order. In a solution of common salt, iron is positive to copper negative; while in ammonia (or hartshorn), iron is negative to copper positive. For all dilute acids, however, the order is exactly the same, and such as we have given it above.

55. *Galvanic Choice of Corrosion.*—It is a curious fact, that if two metals be placed in contact, in an acid which can act on both, only the one which is more oxidisable will be attacked. In the galvanic pair, the zinc only is eaten away, though the acid would act on the copper if no zinc were present. Hydrochloric acid (or spirit of salt) acts readily on iron, but much more readily on zinc. If, then, a piece of zinc and iron be put in the acid, and made to touch, the zinc will be all dissolved before the iron begin to be corroded.

Another illustration of the same fact is seen in the action of sulphuric acid on zinc itself. If the zinc of a galvanic pair be pure, the acid scarcely acts on it at all until the circuit is complete; but if it be impure, then, as soon as it enters the acid, there is a strong effervescence. The reason is, that the other metal particles, such as lead, carbon, iron, etc., present in the zinc, form with it just so many closed galvanic circuits, and the zinc wastes rapidly away. This *local action*, as it is technically called, causes not only a useless waste of zinc, but also a serious enfeebling of the current. Pure zinc would be far too expensive to use for galvanic purposes; but happily it is found that *amalgamating* the plate, or rubbing some mercury over its surface, renders the ordinary commercial article as good as the pure zinc for the purpose.

56. *Comparison of Voltaic and Frictional Electricity.*—Although the electricity of galvanism is undoubtedly the same natural agency as that of the machine, there is a marked difference between the two, of which it is important to have a clear conception.

The difference is expressed by saying that, in the voltaic current, we have a large amount or *quantity* of *very feeble* electricity; while, in the electricity of friction, we have *great intensity or tension, but no great quantity.*

A very good illustration of the distinction between intensity or tension and quantity is furnished by the allied excitement of heat. The temperature of a body may be called its *heat-tension*, and has very little reference to the *absolute quantity* of heat-motion or excitement possessed by the body. A red-hot poker, for example, has heat of a very high tension, though the quantity is very much less than that of a warm-water bath. And the difference between the properties of voltaic and frictional electricity is not perhaps greater than between the properties which belong to heat of weak and of strong intensity. A small wire, made red-hot, will suffice to burn the finger or explode gunpowder, though an infinite quantity of heat applied at low tension has no such effect.

The electricity of friction is in the static or reposing state, stored up ready to burst forth in a short sharp rush; the galvanic action is a steady torrent of the electric agent, and thus better suited for doing work in its passage than the former. In modern language the former is *potential* or possible electric energy, the latter *kinetic* or actual moving energy.

GALVANIC BATTERIES.

57. *A Battery.*—When a number of galvanic pairs, such as we have described, are put together, so that the currents given by each shall all unite and flow in the same direction, they form a galvanic battery. The copper plate of each cell (fig. 21) is connected, by a strip of copper, with the zinc of the next, so that we have a zinc plate left alone at one end, and a copper at the other. These are called the poles or electrodes of the battery, and the circuit is completed by joining the poles with a wire or conductor. The group thus acts exactly as a compound galvanic couple, the copper plate being the positive pole, and the zinc the negative; and the electro-motive force of the arrangement, or its power to push on the electric wave, is just as many times greater than that of a single cell, as there are cells so linked together. In the connecting wire, and in all the parts of the circuit out of the liquid, the direction of the current is *from the copper to the zinc*, as in the case of a single cell.

58. *Requisites of a good Battery.*—The objects to be attained in a battery are chiefly two: first, that the strength of the battery, and, therefore, the electro-motive power of each cell, should be as great as possible; and second, that the battery should be able to keep up steadily, and for a long time, its original strength. The first condition must be provided for by selecting metals widely apart in the electro-chemical list, and by avoiding *local action.* As to the second condition, it is not such an easy matter to secure a battery uniform in its action. Several causes operate to impair its strength in course of time. The acid gets weak, and must be strengthened from time to time. Another injurious influence is at work when the plates are placed in a single liquid, and face each other directly. This is a tendency of particles of the one plate to pass to the other, and so to reduce that difference in the surfaces which is essential to the action. In the copper-

zinc couple, for example, the dissolved sulphate of zinc forms a deposit on the copper plate, while some of the copper also passes to the zinc; so that in course of time the two surfaces become almost alike, and the current almost nothing. This is a grievous fault, but, as we shall see, it can be prevented by placing a porous partition between the plates. It gets soaked with the liquid, and so allows communication to pass; yet it is close enough to prevent the exchange of metallic particles.

Besides these, there is another very serious cause of weakening, which requires special provision. It is known as *polarisation of the plates.* In all batteries where hydrogen is set free at the negative plate, there is a tendency of the hydrogen bubbles to adhere to the plate, and a rapid fall in strength of current is the result. The hydrogen not only forms a non-conducting layer over the surface of the plate, but, what is worse, gives rise to a *counter* or a *secondary current.* This hydrogen deposit is prevented by using *two* liquids in place of one. Both must be conducting, and we must have some means of keeping them from mixing. The liquid in which the *unaffected* or *negative element* is immersed, must be of such a nature that the liberated hydrogen can act chemically on it, and thus be absorbed as fast as it is formed.

VARIOUS FORMS OF BATTERIES.

59. *Cruickshank's Trough Battery* was the first improvement on Volta's pile, of which it is but another form. Pairs of copper and zinc plates, soldered together, are fixed in a wooden trough, coated with some insulating varnish, so as to form a series of water-tight divisions or cells in the trough. The cells are filled with dilute acid, and correspond exactly to Volta's cloth discs. The defects of assimilation and of polarisation of the plates, described above, combine to make this battery unsatisfactory.

60. *Wollaston's Battery* is shewn in fig. 21, and is an improvement on the last. The copper plate is bent up so as to face the zinc on each side. This clearly brings twice as

much zinc surface into action, and so doubles the *quantity* of electricity which each cell will give. Each couple is immersed

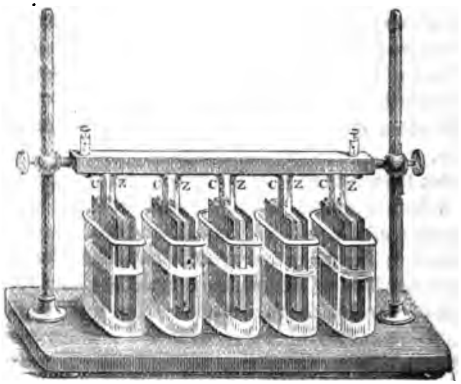

Fig. 21.

in a separate trough, to insure insulation. The zinc of one cell is connected to the copper of the next by a strip of copper soldered to each; and the whole may be raised out of the cells, when not in action, by means of the wooden rod supporting them.

61. *Smee's Battery* is, in general, similar to the former; only, in place of a copper, there is a thin silver plate, which is more electro-negative, and gives, therefore, greater current power. The positions of the plates are also reversed, to save silver, there being a zinc on each side of the silver, and kept from touching it by strips of wood or cork. The zinc plates are bound together by a coupling, to which the connection from the next silver is fixed. Polarisation of plates is lessened by covering the surface of the silver with finely-divided platinum.

62. *Daniell's Battery*, invented in 1826, was one of the first, and is still one of the best arrangements for constancy. It is a zinc and copper combination, the copper being in the shape of a jar, and serving as the outer dish of the cell.

Fig. 22 represents a Daniell's cell. The zinc, *z*, is formed into a rod, and is placed inside a porous jar, *d*, of unglazed porcelain or earthenware, which again stands inside the copper cylinder, *c*. In the porous dish, dilute sulphuric acid (one part acid to 10 or 12 of water) serves to excite the zinc. As a conducting and absorbent liquid, between the porous vessel and the copper, is put a strong solution of the blue crystals known as *sulphate of copper* or *blue vitriol.* Let us have a clear idea of the action of this sulphate of copper solution. It is a beautiful arrangement.

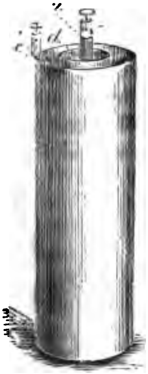

Fig. 22.

Sulphate of copper is what is formed when sulphuric acid acts on copper; and chemistry informs us that, in the process, a molecule of copper expels and takes the place of the molecule of hydrogen which is present in each molecule of sulphuric acid. In ordinary circumstances, the affinity of the copper for the other elements of the sulphuric acid is greater than the affinity of the hydrogen for them. But when any gas is being set free from a previous combination, its *nascent* or new-born state is a most highly active one. Thus, the hydrogen which is being liberated, at the copper plate, from the water of the solution, is able to displace the copper in it, and return to the bosom of the sulphur and oxygen molecules to re-form sulphuric acid. The copper, deposed from its place, is thrown on the copper dish, and instead of hindering the action, as the hydrogen would do, keeps the surface bright with metallic copper, and so constantly fit for service.

The action of the battery is therefore to form sulphate of zinc in the porous dish, and to consume sulphate of copper in the outer. We must keep the solution saturated with sulphate of copper; and for this purpose we may put some crystals of the salt at the bottom of the cell, or on a small shelf of copper gauze near the top of the copper vessel.

63. *Grove's Battery* has a greater electro-motive power than any we have described, the plates being platinum and zinc; but it is inferior in constancy to Daniell's. Fig. 23

shews an excellent form of a Grove's cell. As in Daniell's, we have a porous dish, *d*, but containing, in this case, the platinum plate, *p*, which is bent into the S form seen in fig. 24, to increase its surface. Outside of *d* is the rolled-zinc plate, *z*, standing in a glass, *g*. The liquids used are dilute sulphuric acid in the outer dish, and strong nitric acid in the inner. When the poles are joined, zinc sulphate forms in the outer vessel, and an unhealthy gas (vapour of hyponitric acid) at the platinum plate, which must be kept from escaping by plugging the mouth of the porous dish. The nitric acid absorbs the hydrogen, and prevents polarisation of the plate.

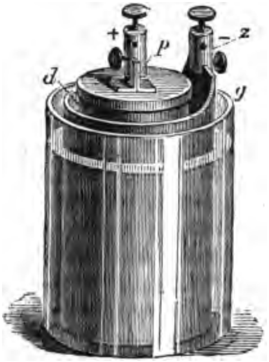

Fig. 23.

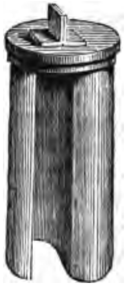

Fig. 24.

Platinum is about four times the cost of silver, and that is the only objection to the battery. But it has the advantage of great power, and is very easy to manage; and the platinum does not get useless, as other negative plates do, by the action.

Iron, it is found, may be used for the platinum, with almost equal effect. Only, care must be taken to keep the nitric acid *concentrated*, as it is only then that it does *not* attack iron.

64. *Bunsen's Battery* was invented in 1843, and is most powerful. It differs, in principle, from Grove's only in the use of a *carbon* or *charcoal* electrode for a platinum one. In

the original form, as devised by Bunsen, the carbon was in the shape of a jar, and the porous dish with its zinc stood inside it. But the modified form, most common in this country, is shewn in fig. 25. The carbon exactly takes the place of the platinum in Grove's element, and a greater quantity of electricity is obtained from the larger zinc surface. Bunsen's is the most energetic of all the constant batteries, and is almost universally employed on the Continent. But it requires very careful preparation, and extreme care in making the carbon connections.

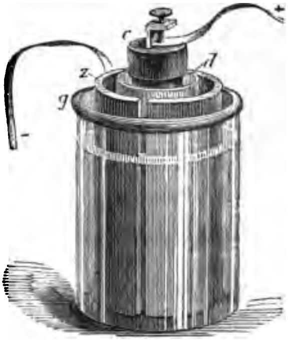

Fig. 25.

A recent improvement (by Faure) is to make the carbon in the form of a bottle, so as to serve at once for the porous dish and the negative element. It is provided with a carbon or platinum stopper, to which the connection is fastened, and which prevents the escape of the fumes. In power Faure's element is said to be superior to either Bunsen's or Grove's.

65. *Recent Forms of Battery Cells.*—The extensive use of the telegraph within the last few years has rendered the possession of a simple and cheap battery of good power very desirable. Many forms of cells have accordingly been suggested, and adopted with more or less success. We have here space to notice only those most favourably received.

66. The *Daniell Trough* has been adopted by the Post-office, and it is said to be a good and economical battery. A wooden trough is divided into cells by glass plates, or varnished slate slabs. These are again subdivided by slabs of porous earthenware. Cast-zinc plates and dilute acid go to one division, while copper and its sulphate go to the other. This action is, of course, identical with that of a Daniell.

67. The *Density Battery* of Callaud is derived from Daniell's principle. Here the porous cell is dispensed with, and the two liquids are kept apart merely by their difference of density or weight. The copper plate is placed at the bottom of the cell among crystals of blue vitriol. A copper wire soldered to it, and protected by gutta-percha, passes up through the liquid to join the next zinc. Over the crystals of copper-sulphate is poured a weak solution of sulphate of zinc, in which the zinc plate is suspended so as not to reach the copper solution. The zinc-sulphate solution is lighter than the other liquid, and so floats on it without mixing. It is said to be very effective, and to give a constant current for months.

68. The *Minotto Battery*, somewhat like the former, has also come into telegraphic use. Coarsely powdered crystals of copper-sulphate are placed at the bottom of the cell, the copper plate being under the crystals. A layer of clean sand (or even sawdust) is put over the crystals, with a piece of cloth or porous paper between, to prevent mixture.

The cell is fixed with acid water, and a plate of unamalgamated zinc laid on the sand, or hung perpendicular to the face of the copper plate.

69. *The Marié-Davy* or *Sulphate of Mercury Battery* is a Bunsen battery with another liquid in place of nitric acid in the porous dish. This is a solution, or paste rather, of the white crystalline bisulphate of mercury. Sulphate of zinc is, of course, formed in the outer jar, while metallic mercury is deposited on the carbon, and, from its weight, falls to the bottom of the jar. Any sulphate of mercury passing through the porous dish will do no harm, as it will only amalgamate the zinc. The arrangement is powerful and ingenious, but it is rather expensive. A battery of eight cells gives as strong a current as twelve of Daniell's, but, with steady action, it falls much more rapidly than Daniell's. For interrupted work, such as telegraphy or ringing of bells, it is better suited, and will serve for three or four months.

70. The *Leclanché Battery* is the last we shall mention, as it is one of the most recent, and perhaps one of the most successful. It is a zinc-carbon combination. The carbon

or negative plate is put in a porous jar, filled with a mixture of gas-coke or carbon, and the black dioxide of manganese. Both the carbon and manganese have first to be broken and sifted free from dust. For the zinc liquid there is a solution of common sal-ammoniac (or chloride of ammonium). Chloride of zinc is formed in the zinc dish, and this is soluble in the sal-ammoniac solution. In the other jar, the dioxide of manganese is reduced to a lower oxide, and ammonia is formed in small quantities. This cell has great electromotive power, ten of it being as powerful as sixteen Daniells, and it is thus specially suited for long lines of telegraph. It requires very little attention, and the zinc and chemicals need renewing only about once a year.

GALVANOMETRY OR MEASUREMENT OF CURRENTS.

71. *Œrsted's Discovery.*—We shall now explain how we can detect this invisible galvanic flow, and how we can measure it and say that one current is stronger than another. Œrsted, a professor at Copenhagen, discovered in 1819, that if a wire be brought directly over a magnetic needle and a current be sent along the wire, the needle will instantly turn aside from its north and south position. The amount of the deflection is a measure of the strength of the current, though it is not proportional to it. Also the side to which the needle swings defines the direction of the current, according to the following very simple rule (known as Ampere's rule): *A person supposed to be swimming with the current in the wire, and having his face to the needle, sees its north pole turn to his left.* This always supposes the current-wire to lie in the magnetic meridian.

From this rule, it is obvious that a current passing *above* a needle turns it to the same hand as an *opposite* current does *beneath* the needle. But by *doubling* a conducting wire, so as to be first over and then under the needle, we have clearly the same result. One current will act twice on the needle, and each time to turn it to the same side. So, by bending the wire round and round the needle, and keeping the different turns separate, we can multiply the effect of the same current to any desired degree. This, then, is the principle of the *galvanometer multiplier*, or *galvanometer*, the instrument by means of which we detect the presence of a current and form an idea of its strength. There are three forms of it on this principle.

72. The *Simple Galvanometer* consists of a magnetic needle poised or suspended delicately over a graduated card, and placed within a coil of *insulated copper wire*, so that its oscillations can be seen. Wire is insulated by being covered with gutta-percha, or by being overspun with cotton, or, far better, silk. This is found to be quite sufficient to prevent the low tension electricity of the current passing from one turn of the wire to another.

73. The *Astatic Galvanometer* is the form most commonly used for detecting very feeble currents. In place of a single magnetic needle, an *astatic pair* is employed. An astatic pair of magnetic needles is simply a pair of similar needles, with their poles turned opposite ways, and stiffly connected at their centres, so that both will swing together. The one tends always to turn in an opposite direction to the other under the earth's magnetic attraction. If, therefore, they were perfectly alike, we should have a perfectly *astatic* pair, or pair without *set;* that is, they would remain indifferently in any position, neutral to the direction of the earth's axis. But in practice we never have this perfect neutrality.

The figure (fig. 26) shews how the astatic pair is used to form an astatic galvanometer. One needle swings within, and the other without the coil, and we have thus a double improvement on the single needle. First, the magnetic force keeping the needle in its north and south position is very small; only the difference of magnetism in the needles. Second, the current acts again on the outside needle, turning it to the same hand as the inside one, as Ampere's rule at once shews. By such an arrangement,

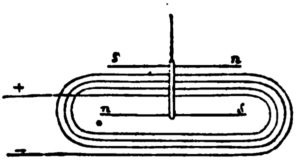

Fig. 26.

then, a galvanometer of extraordinary delicacy may be obtained. Fig. 27 shews the usual form which is given to the instrument.

Round a bobbin, AB, of ivory is wound a coil of fine, silk-covered copper wire. The number of turns and thickness of wire depend on the use we are to put the galvanometer to. About six hundred or eight hundred suffice for all ordinary purposes, but for some delicate experiments as many as thirty thousand turns have been made. A slit is usually left in the coil, to admit the lower needle; and the upper needle moves over a graduated circular rim. The whole is protected by a glass cover from the disturbance of the air, and rests on a stand supported by three screws, for levelling the instrument, that the needles may hang free. When used, the bobbin is turned round by the screw, Q, until the needle stands at the zero-point; and the wires through which the current is sent are fixed to the binding screws, *s*, *s′*, which communicate with the ends of the bobbin wire. The number of degrees that the needle deflects may then be read off, and this gives an idea of the strength of the current. It is to be observed, however, that twice as great a deflection does not shew twice as strong a current, because for different angles of deflection the coil is differently situated towards the needle. Still, we are sure that a greater deflection indicates a stronger current; and for about 20° on each side of the zero, the strength may be taken as proportional to the angle of deviation.

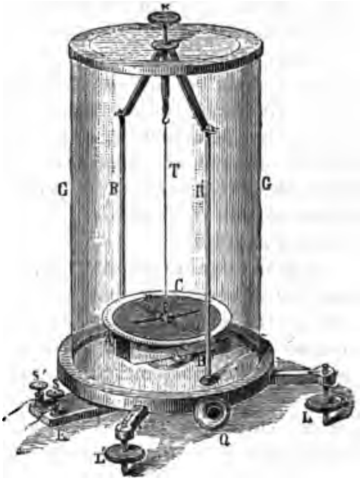

Fig. 27.

74. The third form of galvanometer multiplier is called

the *Differential Galvanometer.* It is used for comparing the strength of two currents, and is a simple modification of the last.

75. These three are, however, rather galvanoscopes, current detectors than current measurers. For estimating strength, the *Tangent* and *Sine Galvanometers* are of more ready and practical use; but we have not space to describe them.

The *Reflecting Galvanometer* of Sir William Thomson is by far the most delicate of all such instruments. It was invented by him in connection with the Atlantic Telegraph, and belongs rather to the subject of *Submarine Telegraphy.*

76. *Current Strength and Current Resistance.*—The strength of current given by a battery or cell does not depend alone on the electro-motive force of the battery or cell. We estimate the strength or electro-motive force of a battery by the amount of *statical charge* in its poles; that is, by the amount of attraction or repulsion they can produce. Thus the *strength of a battery* may be defined as *its power to propagate electricity or push forward the polarisation against resistance.*

Now in certain circumstances the current given by one cell may be as strong as that given by a hundred of the same cell joined together as a battery. It all depends on the nature of the route the current has to traverse. Bodies differ to an almost incredible degree in the resistance they offer to the passage of a current. And part of the power of the current is spent in overcoming this resistance, and *disappears as heat.* Thus the current is weakened in the same degree as it is resisted, and the strength of current given by a hundred cells will be no greater than that given by a single one, if the resistance in the former case be a hundred times greater than in the latter. In the former case the single cell would most likely be utterly unable to push its charge along the course, and its current would therefore be interrupted.

77. For telegraphy and other applications of galvanism, the determination of the relative resisting powers of metals is a matter of great importance. But it is a matter of extreme

difficulty, for purity of metal and even temperature have a great effect on it. Thus $\frac{1}{8}$th per cent. of iron present in copper will increase its resistance to the current by as much as 25 per cent. Silver offers the least resistance of all our conductors, and copper the next smallest. The other metals follow in this order—gold, zinc, platinum, iron, tin, lead, mercury. Between silver and mercury there is a wide difference in resisting power; mercury offers fully sixty times the resistance of silver. But between the metals and liquids there is a yet wider difference. For if copper offer a resistance of 1, then dilute acid offers a resistance of 1 million; a solution of copper-sulphate, of 17 millions; and pure water has the almost incredible resistance of 6700 million times that of copper.

The law which the resistance of wires has been found to follow is, that it is greater the greater the length of the wire, and less the greater its area of cross section. Or, in more precise language, ***the resistance is proportional directly to the length of a wire, and inversely to the area of cross section or square of its diameter.*** Thus, we should have as strong a signal by a telegraph wire $\frac{3}{8}$ inch diameter, and nine miles long, as by a wire $\frac{1}{8}$ inch diameter, and only one mile long.

EFFECTS OF THE GALVANIC CURRENT.

78. These may be classified as mechanical, magnetical, physiological, heating, luminous, and chemical.

The first two classes of effects will be described under the distinct head of Electro-magnetism. We have seen that the physiological were the first observed effects of the current. They will be more particularly noticed under Animal Electricity, to which Galvani's experiment properly belongs. It is remarkable that when the current passes through the human body, nothing is felt except at the beginning and end of the current flow. It is the sudden change of tension that affects the nerves; and this is the reason why the frictional shock is more painful than the galvanic. A battery of fifty Bunsen cells may be handled with little inconvenience. Only this is so far owing to the insulating nature of the skin. If we wet our hands with salt water, the effect is greatly increased; and a very *weak* current will be felt if we let it enter by a cut in the skin.

The senses may be readily affected by the current, especially those of taste and sight. If we put a half-crown under, and a piece of zinc above the tongue, a peculiar salt taste is perceived whenever we make them touch. When the pieces are put between the gums and the cheeks, a flash of light is seen each time they are joined. The nerves of hearing are not so quick, but with the poles of a battery of thirty cells inserted in the ears, it is said that a continuous noise is heard.

79. *Heating Effects.*—When a current passes through a thin wire, the wire becomes heated, more or less according to the strength of the current and the resistance of the wire. A fine steel wire, which offers great resistance, may be made white-hot, melted, or dissipated into vapour. Even platinum, which cannot be fused by the heat of a furnace, may be melted and volatilised by a battery of thirty to forty Bunsens.

A useful application of the heating power of the current has been made to the firing of gunpowder. If the wires from a battery communicate with a fine steel wire embedded among gunpowder, the passage of a current will heat the steel red-hot, and produce an explosion in a moment. This principle has been employed with great success in the construction of cartridges for use in blasting operations, and they have become very common on account of their safety and certainty of working.

80. *Luminous Effects.*—When the wires from a powerful battery are brought near to each other, no current passes till they touch. On separating them, a bright spark passes, due, as we shall afterwards see, to *induction.* Nor does the current cease after a *small* separation. It forces its way across the short interval of air, producing a brilliant light, and a heat so intense as to melt the most infusible metals. The ends of the wires will therefore be burned away, and we must seek for some more infusible conductor, in order that the current and the light may continue. This is found in the various kinds of carbon, such as charcoal, coke, etc. By far the best form of carbon for this purpose is the charcoal deposited in

the retorts of gas-works. The carbon is formed into pointed sticks or pencils, to fit two metal-holders such as are shewn in fig. 28. They can be adjusted to any distance by sliding-rods, to which they are fixed, and which communicate with the wires of the battery. When the current is on, and the points separated by one-tenth of an inch or so, a most dazzling light is produced, rivalling that of the sun in purity and splendour. It is too bright for the eye to examine it; but an image of the points can be cast on a screen, and then there will be seen, as in the figure, an arch of flame between the points. This arch of flame, or the *voltaic arc* of the electric light, is composed of white-hot particles of charcoal flying from the one pole to the other. The positive pole gradually gets hollow, while the negative remains pointed, apparently by the addition of matter.

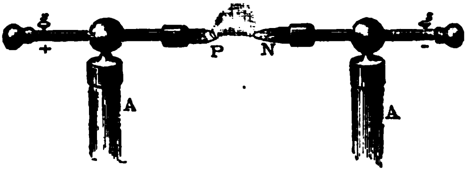

Fig. 28.

The heat of the voltaic arch is the most intense that can be artificially produced. Platinum melts in it like wax in the flame of a candle. Quartz, lime, and magnesia are fused by it; and the diamond itself is not only fused, but reduced to a black mass like coke.

As the carbon points waste away, and the positive much more rapidly than the negative, some arrangement is necessary to keep the points at such a distance that the current can pass, and so the light continue. This is the object of the *electric lamp*. Various forms of it have been invented. One of the most celebrated was made by Foucault and Duboscq, and is a beautiful clockwork contrivance. But simpler contrivances have since been adopted.

Attempts have been made to use the electric light for street illumination in cities, but the great care and cost required for its production and regulation throws it out of competition with coal-gas. It is, moreover, rather two dazzling a light for such a purpose, as it contrasts too painfully the extremes of light and shadow. But it has been used with excellent effect where a limited space had to be lit up for a few nights, as in the construction of bridges across rivers and the like.

For lighthouses it is specially suited, and has been successfully adopted in many of them. That at Dungeness has been lit up with it since 1862; and that at La Heve, near Havre, since 1863. It is decidedly superior to oil-lamps in such cases, as its illuminating power is very great, and remarkably penetrating in hazy weather.

81. *Chemical Effects.*—When a current passes through a liquid, composed of two or more simple elements, there is in general a separation of the elements or a decomposition of the liquid. *Electrolysis* is the name given to this decomposition, the liquid so broken up being called the *electrolyte.*

The analysis of water by the current may be taken as the type of electrolytic action, and a very simple method of shewing this is seen in fig. 29.

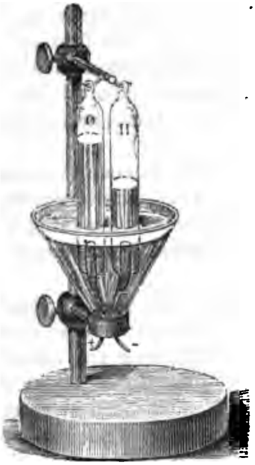

Fig. 29.

Two slips of platinum are soldered to two copper wires, which are passed through a cork at the bottom of a glass basin. The basin is filled with water, slightly acid to make it conducting. Now when the platinum plates are connected with the wires from a battery, the liquid is polarised, oxygen going to the positive plate, and hydrogen to the negative. If the current be strong enough, these elements will be separated from the liquid, and as platinum combines with neither, each will bubble up at its platinum pole. They may easily be collected separately by filling two glass tubes with the acid water, and inverting them over the plates.

Doing this, we find that the hydrogen is produced in twice the quantity of the oxygen, and learn the important fact, that *elements are decomposed by electrolysis in the very same proportion as they are united in the compound*, for water, we know, has two atoms of hydrogen for each of oxygen.

82. Faraday called the two poles at which the elements appear, the *electrodes*, that is, electric ways, the positive pole being called by him also the *anode* (or *up* way), and the negative, the *cathode* (or *down* way). The element that goes to the anode he called the *anion* (or *up-going* one), and that to the cathode, the *cation* (or *down-going* one). In the case of water, oxygen is the anion or electro-negative element, and hydrogen the cation or electro-positive one.

It is to be noted that a *single cell* can never decompose water, or any electrolyte ; at least two are required to overcome the polarisation of the plates or counter-current which the anion and cation tend to set up. The greater the strength of the current, the more rapidly are the elements liberated ; and the quantity of gas given off corresponds exactly to the current power.

83. *Faraday's Voltameter* is the practical use of this for current measurement, and its value is that it gives us a *uniform standard* for comparison of currents. The gases are collected either together in a single tube, or each in a separate one ; the tubes are graduated, and the number of cubic inches of gas which a current gives in a certain time, say a minute, is an exact measure of its power.

84. Any other substances, if in a liquid state, composed of two elements, a metal and a non-metal, can be broken up by the current exactly like water. The metal always corresponds to the hydrogen, and goes to the negative pole.

In the electrolysis of a solution of a salt, such as copper-sulphate, we have an interesting case. If two platinum poles are put in a solution of this, pure metallic copper is deposited on the negative pole, and free sulphuric acid and oxygen appear at the positive ; and layer after layer of fine copper-dust will be showered on the negative plate, so long as the sulphate of copper lasts. In the same way with a solution of nitrate of silver, pure metallic silver will be deposited on the negative pole, and acid and oxygen on the other. All the common metals, gold, silver, platinum, copper, zinc, etc., can be deposited in this manner.

85. *Electro-metallurgy* is the practical application of this power of the galvanic current to precipitate a metallic layer on any surface which forms a negative electrode of a battery or cell. It is divided into two sections—*electro-typing*, where the coating of metal must be firm, and has to be removed from the surface, and *electro-plating*, when it is to remain fixed on the surface.

(1.) *Electro-typing* is the process by which seals, medals, engraved plates, ornaments, etc., can be most accurately copied, and reproduced in metal, more especially copper. We can best explain how this is done by taking a particular instance.

Suppose we wish to copy a seal in copper. An impression of it is first taken in gutta-percha, sealing-wax, fusible metal, or other substance which takes a sharp impression when heated. A wire to convey the current is stuck into the impression while soft, and, if the surface be non-conducting like gutta-percha, it is brushed over with plumbago or black-lead. Then it is attached by its wire to the negative or zinc pole of a weak Daniell's cell, while a plate of copper is attached to the other pole. The two are immersed in a strong solution of copper-sulphate. Gradually, the copper from the sulphate is deposited on the black-leaded surface, until in a day or so a tolerably thick plate is formed. It may easily be detached by the point of a knife, and then we have a faithful copy of the original seal to the minutest line.

But we may even do without a battery cell altogether, and make a galvanic pair out of the object to be coated and a plate of zinc.

Electro-typing is of great importance to the engraver. Copper plates may be multiplied to any extent; and wood-cuts, which would soon become useless, if printed from directly, can be converted into copper plates. Indeed, nearly all the illustrations in popular works are now printed from electro-types.

(2.) *Electro-plating* is the art of coating by the galvanic current the baser and cheaper metals, such as brass, bronze, copper, nickel-silver, etc., with the more precious ones, such as silver and gold. Theoretically, the process is simple enough, but practically, it requires much experience and skill. When an article is to be electro-silvered, it is first thoroughly cleansed, and then washed with nitrate of mercury. This leaves a thin film of mercury, which acts as a cement between the article and the silver. It is then put in a silver bath, a weak solution of cyanide of silver in cyanide of potassium, and attached to the negative pole of a battery; while a silver plate is attached to the positive, to keep the solution, by its decomposition, from getting poor. The process of electro-gilding is very much the same; only the article first gets a layer of copper by electrolysis, and is then immersed in a gold bath. A piece of gold is suspended from the positive pole, and the bath must in this case be kept hot.

ELECTRO-MAGNETISM.

86. We have seen that the galvanic current acts by attraction or repulsion on a magnetic needle, and we shall now give the general laws according to which this action takes place. These form the subject of *Electro-magnetism.*

The influence of currents on magnets is mutual; magnets act on movable conductors conveying currents, just as currents do on movable magnets. And not only so, but currents also attract and repel each other according to laws which are very well known. They are usually treated separately under the head of *electro-dynamics*, but we have here included them under electro-magnetism, because the connection between magnetic and current action is so close that there is no reason but to refer them to one and the same ultimate cause. For, we shall see, that every case of magnetic action —whether of magnets or currents, currents on magnets or magnets on magnets—can be at once explained by the theory that magnetism is due to electricity in current.

87. *Laws of Current Action.*—These laws, which are thus at the foundation of electro-magnetism, are two, though one is practically included in the other.

(1.) Two parallel wires, capable of motion, or two flexible conducting chains, *attract* each other when currents pass along them in the *same* direction, and *repel* when they pass in *opposite* directions. (2.) Two wires or chains, not parallel, but crossing each other, attract when the current runs in *both*, either to or from the point of crossing, but repel when it flows in one to, and in the other from, this point.

These laws are easily proved by experiment with light frames of copper wire. They must be nicely movable upon pivots, and at the same time allow the current to pass round the frames without interruption. Many mechanical actions can be produced by the application of the two laws we have given. For example, a current flowing in a circle, may be made to cause a constant rotation of a wire conveying a current at right angles to the former. A similar rotation may be produced by putting for the circular current, in the last case, a pole of a magnet. In fact, the mutual action between a current and a magnetic pole is such, that if either be fixed and the other movable, there will be a constant rotation of the one round the other; and a change in the direction of the current, or in the pole of the magnet, will reverse the direction of rotation.

88. *Ampere's theory of magnetism* furnishes the key to these actions, and forms the link between magnetism and current electricity. According to Ampere, magnetism is due to currents circulating round the particles of a magnet, and *all in the same direction.* The want of magnetism in a steel bar is simply owing to the currents flowing in all different directions, and so neutralising each. Fig. 30 shews a section of a magnetic bar with its currents all flowing one way. These are manifestly equivalent to one strong current flowing round the bar, as in fig. 31, for the internal currents destroy each other. Magnetisation is

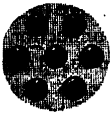

Fig. 30.

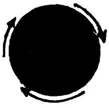

Fig. 31.

perfect when the currents are exactly parallel, and *coercitive force* is the resistance to this parallel disposal of the currents. Soft iron is more perfectly magnetic when under induction than steel, because iron has less coercitive force.

If this theory be correct, then we should find that circular currents should have magnetical properties. And so we actually find it. When a current passes through a helix or spiral of copper wire it becomes exactly like a magnet. Each end has an opposite polarity; if suspended delicately, it will point north and south like a magnet; and spiral currents act on each other and on magnets in every way as magnets do.

The nature of the poles is determined by the direction in which the current flows round the axis of the spiral. If, on entering the spiral, the current flow in a direction opposite to the hands of a watch, the spiral is said to be *left-handed*, and the N. pole will be as indicated in fig. 32. If it go with the hands of a watch, it is *right-handed*, like a common screw, and the poles are as in fig. 33. This is in accordance with Ampere's rule; for, if we imagine one swimming with the current and his face to the axis of the spiral, the N. pole is always on his left. In general, then, if we look along the axis at the pole of a magnet, it will be a *south* or a *north* pole according as its currents are seen to flow in the *same* or *opposite* direction to that of the hands of a watch.

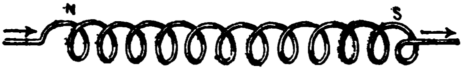

Fig. 32.

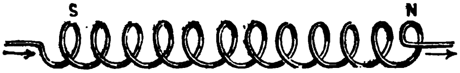

Fig. 33.

89. *Electro-magnets.*—Perhaps the strongest proof of Ampere's theory is that a piece of soft iron, placed within a spiral current, becomes *for the time* powerfully magnetic.

If bars of steel be placed inside, they are *permanently* magnetised; and a spiral current is thus a very ready and powerful means of magnetisation. Where powerful magnets are required, this is by far the best way of making them, and there is nothing easier: a few turns of insulated copper wire conveying a current will at once convert a steel bar into a magnet by merely passing it over the bar.

Magnets produced by the action of the current on soft iron are termed electro-magnets. They far outrival permanent magnets in strength; and their value lies in this also, that we can change their poles, or make their magnetism come and go in a moment, as if by magic. If the iron core be very soft, its power is gone the instant we stop the current; but if it is not quite soft there is always more or less *residual* magnetism left in the bar after we stop the current.

Electro-magnets are generally made of the horse-shoe shape, as in fig. 34, and it matters not whether the coils be wound all over the magnet, or accumulated at the two ends. The power depends only on the number of turns of the coil, and the strength of the current. But there is, of course, a limit to the number of turns; for the advantage of increasing them may be counteracted by the weakening effect of the long wire on the current. The wire which is wound on the core should be thick, so as to be of small resistance, and covered either with silk or cotton. For ordinary sizes, the latter is sufficient, as the electricity most suited to develop magnetism is of small tension and easily insulated. Usually, it is wound not on the core directly, but on two pasteboard cylinders or bobbins, which can be taken off the magnet at pleasure. With a very thick core, a sufficient number of turns, and a strong battery, we may have any power of electro-magnet. Some have been made capable of sustaining several tons'

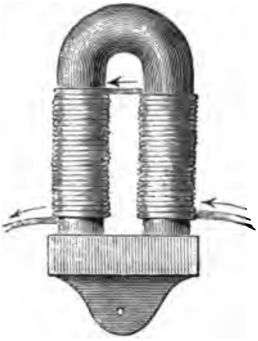

Fig. 34.

weight. By far the largest that has ever been constructed is one made for Lord Lindsay. It is said to weigh over 6 tons, and to have 14 miles of copper wire, ¼ inch thick, wound on its core. The exciting battery is equally colossal, consisting of 150 Grove's elements, each exposing a square yard of platinum surface. This gigantic size has never before been approached.

90. Electro-magnetism has many valuable practical applications. We owe to it our system of telegraphy, which alone would make this science of surpassing value. Its importance requires us to give it special attention.

Electricity has besides been applied with success to the driving, and especially the regulating of clocks; so that one good clock may be made to control any number of ordinary ones, and they will keep time to a second with the governing clock.

Electro-magnetic engines have also been constructed, in which the force of current is the motive power, and of course, the zinc of the battery the fuel. The idea was long entertained that here was the future rival of the steam-engine; and a vast amount of labour has been given to the construction and improvement of these engines, among practical mechanicians especially. But as zinc is so many times dearer than coal, it is impossible by any arrangement of mechanism that it can be brought into competition with the latter.

THE ELECTRIC TELEGRAPH.

91. Although the history of electricity and magnetism is full of suggestions for the application of those powers to the purpose of a telegraph, it is only within the last forty years that any practical progress has been made. So cumbersome and expensive were the inventions even of that period, that ten years elapsed before any decided advance was accomplished. But in the thirty years succeeding, the progress of the art and its application to the daily wants of the time have been as rapid as its previous advance had been slow. Our

limits will not permit even a brief glance at the various stages of discovery which have brought the art to its present degree of development.

92. The essential parts of every electric telegraph are four. There must be a *complete circuit* for the current to traverse. The great discovery of Steinheil in 1838, that the earth serves as a return path for the electric current, is, practically, the most valuable contribution yet made to the science, as it at once greatly reduced the cost by abolishing the use of a return wire. The second requirement of a telegraph is a means of generating the electric force. In one class of magneto-electric instruments, the use of a battery is dispensed with, power being generated by two bobbins coiled upon an armature, and rotating continuously over the poles of a permanent magnet. In general, however, the voltaic battery is used, in some of the forms of which a description has already been given. A telegraph requires further a *communicator* or apparatus for producing signals at the sending station; and fourthly, an *indicator* or apparatus for shewing the signals at the receiving end. In some cases these are similar, as in the single-needle instrument of Wheatstone or the type-printing instrument of Hughes; in others they are distinct instruments, as in the Morse, where the signals are sent by a transmitting key, and recorded by the action of an electro-magnet and armature.

93. *The Line.*—An essential in *all* telegraphs being the line or conductor, attention may be first given to it. The following diagram illustrates the mode of carrying a wire or series of wires from one station to another. LL represents the wire, supported on posts, and carried through insulators. In towns, wires are either carried "over-house" or by underground pipes. In the former case the insulators are fixed to roofs or chimneys by means of wooden brackets or poles. When carried by pipes under the street each wire is insulated in the whole of its length by gutta-percha or other suitable covering. The insulators used in over-house or pole lines are of various forms and different materials. White porcelain, brown stoneware, glass, and vulcanite insulators will be found in use, but white porcelain is deemed the most

suitable. The poles are in some countries made of metal, which though more costly in the first instance will prove more durable than timber. Poles of the latter substance are carefully prepared to resist the attacks of damp or insects, and they vary in length and diameter according to the strain they are to bear or the position to be occupied. The number ,of posts per mile must be carefully calculated from the number of wires carried, and the configuration of the track. Railway and canal lines, from their greater levelness and straightness, generally require fewer poles than telegraphs carried by the public roads; and as regards insulation and cost, the fewer the poles the better. The number of poles runs from 16 to 30 per mile of road.

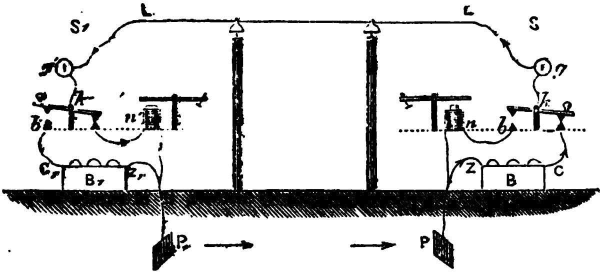

Fig. 35.

The wire chiefly used for inland telegraphy is of iron, galvanised, and of No. 8 ($\frac{1}{8}$ inch) gauge. The "conductivity" of a wire increases, and its "resistance" decreases in the ratio of the square of its diameter. No. 4 wire is, from this cause, used on many of the longer lines.

94. *Instruments.*—Telegraph instruments are of two distinct kinds, namely, those which *record* their signals, and those giving only a transient signal to the observer or listener. Of the first kind there are various forms, comprising instruments which record the message in arbitrary signs (*i.e.*, in the dots and dashes of the Morse alphabet, to be afterwards described), instruments printing in ordinary letters, and others which give an exact *fac-simile* of the message desired to be sent. The non-recording instruments

are the "single-needle," the "bell," the "A B C," or dial instrument, and the "sounder," and, for submarine telegraphy, the reflecting galvanometer.

95. The great bulk of the telegraphing of the world is done by the instrument which bears the name of Professor Morse, and, as already indicated, the Morse consists of a transmitting key and a recording apparatus. The key, in one of its earliest and simplest forms is shewn in the subjoined illustration. The lever, *l l*, moves on its axis, A, and, in the position shewn, it is ready to receive a current from the distant station. This current, coming by the line wire, L, passes through the axis, then through the studs, *n*, *b* (shewn in contact), to the wire E, by which it reaches the recording portion of the apparatus; and thence goes to earth. To send a current, the key is depressed by the handle, H, when the power, originating in the battery, rises by the wire C, through the studs *a*, *m*, and passes to the line wire L, by which it reaches the distant station.

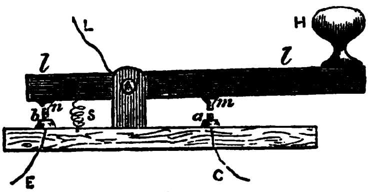

Fig. 36.

96. Electrically the Morse recorder (fig. 37) consists of the electro-magnet E, and the armature F, while mechanically it consists of a lever, G, bearing on its outer end a circular disc, I, and a clockwork arrangement to move forward the tape on which this disc operates. There are, besides, various screws, etc., to adjust the play of the armature and the disc.

97. Before beginning work, the instrument clerk adjusts the screw B, so that the upper side of the disc will press gently on the tape when the stop *f* touches the stud *b*, and the screw A is adjusted so that when the stop *f* presses against it, the under side of the disc dips into the inkwell. The tape, clockwork, and inkwell are not shewn in the figure. These adjustments being made, the screw D is next moved till E will just clear F, when the latter is drawn down

to rest on the stud *b*. Still further, the screw C is used to adjust the spring S, which draws the armature lightly against the screw A, as in the figure.

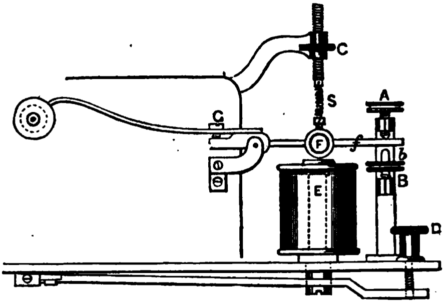

Fig. 37.

98. On a current being received from the distant station, it traverses the coils within E, which, as already described in an earlier paragraph, become for the time a magnet, and draw down the armature. On the cessation of the current, the coils are no longer magnetic, and the spring C at once draws up the armature. With the adjustment of the lever and inking disc already described, a straight mark is made by the disc upon the armature F being drawn down by the passage of the electric current.

The duration of the current thus determines the nature of the record. If the sending clerk depresses the key while he counts *one*, a dot only is made; if he holds it down while he counts *one*, *two*, *three*, the disc will make a dash. Thus, "one, one two three" will produce dot dash (- —), which in the Morse alphabet represents the letter A, and as the alphabet is composed of dots and dashes, the figure and this explanation disclose the whole mystery of telegraphy, as carried out under this system.

99. *Telegraph Codes and Alphabets.*—It will have been gathered from the preceding paragraphs, that several both of the recording and the non-recording instruments speak a special language. In practice every arbitrary instrument

has had its own alphabet, but, so far as Britain at least is concerned, all differences have been merged in the use of the Morse Code. The "double needle" had a "progressive" alphabet, the "bell" instrument had an alphabet based on the desire to complete each letter so far as possible on one bell, while the Morse code was based on the philosophical principle that the letters most frequently used should have the simplest signals.

100. A "progressive" alphabet was more easily learned than one based on such a principle. To know that A was two beats to the left, led on to the knowledge that B was three beats to the left, and so on throughout all the needle alphabet. But in the Morse alphabet, A is "left right," B "right left, left, left," and the one letter has no direct relation in sign to its immediate neighbour. From this circumstance the alphabet was not a little difficult to acquire, and when the British Post Office, at the end of 1869, had to provide for the instruction of several thousand telegraphists, an ingenious grouping of the signs, accompanied by mnemonic phrases, was prepared. The student desiring to learn the masterpiece of cryptography invented by Professor Morse cannot do better than adopt those groups, which are given below:

Group 1 (*all dots*).

·	E, Earwigs
· ·	I, infest
· · ·	S, summer
· · · ·	H, houses.

Group 2 (*all dashes*).

—	T, Turnips
— —	M, make
— — —	O, oxen
— — — —	Ch, cheerful.

Group 3 (*dots and dashes*).

· —	A, A
· — —	W, wet
· — — —	J, jacket's
· · —	U, uncomfortable
· · · —	V, very !

Group 4 (*dashes and dots*).

— ·	N, No
— · ·	D, difficulty
— · · ·	B, baffles
— — ·	G, great
— — · ·	Z, zeal.

Group 5 (*dot, dash, dot, etc.*).

· — ·	R, Remember !
· — · ·	L, law
· — — ·	P, preserves.
· · — ·	F, freedom.

Group 6 (*dash, dot, dash, etc.*).

— · —	K, Kindness
— · — ·	C, conciliates
— · — —	Y, youth
— · · —	X, extremely
— — · —	Q, quickly.

101. The arrangement for signalling figures under the

Morse Code is equally ingenious, each figure being represented by five signals :

1 · — — — —
2 · · — — —
3 · · · — —
4 · · · · —
5 · · · · ·

6 — · · · ·
7 — — · · ·
8 — — — · ·
9 — — — — ·
0 — — — — —

These are the numerals printed long, but on busy circuits expert clerks adopt the practice of "sending short," omitting all after the first dash in 1, 2, and 3, and all before the last dash in 7, 8, 9, and 0.

102. It is stated that Professor Morse founded his alphabet upon information given him by his brother, a journalist, as to the numerical relation of the letters in the English alphabet, the simplest signal, a dot, being given to E, and the next simplest, a dash, to T, those letters occurring most frequently in our language, while Q, X, Y, and Z, had the most elaborate symbols.

103. In the practical work of telegraphy, many arbitrary signs and contractions have come into use. Every telegraph station in the United Kingdom, for instance, has its code signal, and as regards the larger towns the code is expressed in two letters.

There is no office called "London," for the simple reason that the metropolis is a microcosm rather than a single city. The central station, Telegraph Street, is still so called, though removed from that street to the new building at St Martin's-le-Grand. Nevertheless the heart of the telegraph system bears, in the code, TS. as its distinguishing symbol. It is obvious that by no name, Central Head Office or otherwise, could the station be so briefly distinguished as by this symbol, which forms only (— · · ·) in the Morse code. In like manner Edinburgh is EH., Glasgow, GW., Dublin, DU., Liverpool, LV., Belfast, BE., Aberdeen, AB., and so on. After the principal towns have used up all possible two-letter symbols, the other offices are shewn in three letters each. There is a wide margin remaining, after giving each office in the kingdom two or three "code letters" before the possible combinations of the letters are exhausted.

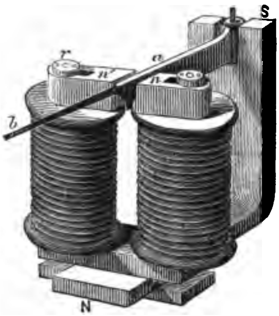

Fig. 38.

104. *The Relay.*—In working a long circuit, it has been found that, owing to leakage, etc., great battery power is required to work the armature of the receiving instrument by the current itself. The use of the "relay" enables a feeble current to do the work by bringing a "local current" into play at the receiving station.

Siemens' Polarised Relay, which is in extensive use in this country, is shewn in the following figures, from which its mode of operation will be understood. Fig. 38 shews the relay in perspective, and in fig. 39 it is seen in plan.

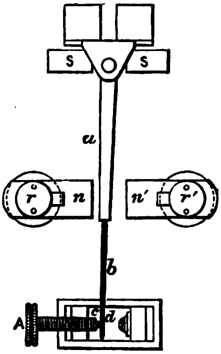

Fig. 39.

The letters NS shew a hard steel permanent magnet, in the south end of which a soft iron armature, *a*, is pivoted, having a free motion right and left. To this armature a thin tongue of aluminium, *b*, is attached, which on touching the point *c* (fig. 39) completes the local circuit. To the north end of the permanent magnet the soft iron cores of the electro-magnet are fixed, as seen in the figures. The permanent magnet induces north magnetism in the electro-magnet, and south magnetism in the armature playing between the points *n* and *n'*. When the armature *a* is midway between the pole-pieces *n* and *n'*, it is equally attracted by both; but, if it be brought nearer the one than the other, it is attracted and held, influenced by the greater force. By an adjustment of the pole-pieces and the contact points *c*, *d*, the aluminium tongue is held against *d* when no current is passing.

The effect of a current from the sending station upon the electro-magnet, is to strengthen the north magnetism in *n* and to diminish that of *n'*, and the armature *a* is drawn over to the contact *c*, by which means the local circuit is completed, and the local battery and printing instrument are brought into play. On the reversal of the key at the sending station, the magnetism in the electro-magnet is reversed and the tongue is attracted back to the point *d*. Thus a current, however feeble, is able to actuate the tongue of the relay, and the completion of the local circuit brings the powerful current of the local battery into play. The relay can be used so that an intermediate station, while recording the message if required, sends the current on with renewed vigour to a more distant station.

105. *The Hughes Type Printer.*—This instrument prints the messages in Roman letters, and its character is more mechanical than electric. An elaborate mechanism is provided, by which type wheels at each instrument are made to revolve rapidly and *in unison*, and the letters are printed at both ends simultaneously by the passage of a single wave of electricity for each letter.

The instrument has a key-board, in alternate black and white keys, and each key—representing a letter or figure—raises when depressed a small contact-pin in a circular plate. Revolving over this plate is a horizontal arm, which in the course of its revolution comes into contact with any pin which may have been raised, and completes the necessary metallic circuit. At the instant of this contact the wave of electricity passes to the distant station. The motions of the type wheels at the two stations are synchronous, and the electric current causes a lever to press the paper slip against the revolving type wheel, at both stations simultaneously.

The clerk sending a message with this instrument reads it off while sending, and can thus check his work. The defect of the instrument is its delicate mechanical adjustment, as any retardation causes a wrong letter to be printed; and when this occurs, both operators must bring their instruments to zero and begin again. It can be used on well-insulated lines of moderate length, and when used under favourable circumstances gives results of surprising accuracy and rapidity.

106. *Non-Recording Visual Instruments.*—Non-recording instruments are made to attract either the eye or the ear. In the "single-needle" instruments—of which about 4000 are in use in the British telegraph department, and which are largely used on railway lines—the signals consist of the movements of a needle vertically suspended. There are two needles connected astatically one within the coil, and the other shewing the motions on a dial outside. Loaded slightly to cause them to hang vertically, the needles are deflected to right or left by the passage of a current through the coil. The newer needle instruments are worked by two keys like those of a piano, the depression of one key causing a deflection to the left, and that of the other key a deflection to the right. Where speed is of importance, the clerk watching the signals is furnished with a writer to take down the message. Beginners "send to understand," that is, a pause is made at the end of each word, and the receiving clerk sends a signal "understand" if he has caught the word. But with experienced clerks this is not necessary, and considerable speed can be attained. As in the Hughes instrument, the single-needle clerk produces signals on his own instrument simultaneously with those on the distant station.

107. This is also true of the dial or A B C instruments, of which the magneto-electric apparatus of Sir Charles Wheatstone is the type used in this country. In Wheatstone's A B C the battery is dispensed with, power being generated as already mentioned by two bobbins rotating over the poles of a permanent magnet. Turning the handle below with one hand, the operator presses down one or other of a series of buttons placed in a circle, and moving levers below, by which the passage of a current is regulated. Above the sending apparatus is a small dial, on the face of which an index—like that of a "centre seconds" watch—flies round, stopping at the letter corresponding to the button depressed at the other end.

108. *Non-Recording Acoustic Telegraphs.*—The chief of those are the "Bell" and the "Sounder." Previous to the

introduction of the fast-speed automatic instruments to be next described, expert telegraphists came to rely on the ear alone, the click of the Morse instrument speaking a language which was quite intelligible to a practised ear. In "sound reading," the great advantage is that the eye is relieved from any duty but that of writing the message.

In Sir Charles Bright's "Bell" instrument, most excellent results in point of speed have been obtained. Two bells of different tone are placed so that the clerk, bending forward to write his message, catches the sound on one side or the other, and translates the tinkle of the bells as they ring out the words. At one time the "bell" instrument had a code or alphabet of its own, the principle of which we have already adverted to, namely, to complete each letter as much as possible on one bell. Now, however, the Morse code is used, a beat on the left bell representing a dot, and one on the right bell a dash.

109. It is a common practice in the larger offices to place a bell instrument in circuit with a number of single-needle instruments at the rural offices around. The sending keys are the same in both instruments and the advantage of the arrangement is, that the experter clerks at the larger office can take off a message at any speed, writing by the ear, while in sending out messages to the smaller offices the speed can be regulated to the local clerks' power of reading the needle.

110. The "Sounder" (or American Sounder, so called from its great prevalence in the United States) consists simply of the electro-magnet, armature, and spring of the Morse instrument (see fig. 37), and the expensive clockwork of the recording instrument is done away with. In the "bell," difference of sound, and in the "sounder" difference of duration of sound, is made to indicate the dots and dashes of the Morse alphabet.

111. *Automatic Telegraphy.*—The speed of all the instruments described is necessarily limited. On the "single-needle," words cannot be sent quicker than the eye can translate them, while on the "bell" and "sounder" the ear must take the sounds only as rapidly as the hand can write

them. In the Morse instrument, the printed slip preserves a record, so that the sending may be in advance of the writing at the other end. But the speed is limited to the rapidity with which the hand of the operator can move the key.

112. We are indebted to Sir Charles Wheatstone for an apparatus which trebles, and in some cases quadruples the capacity of a wire, securing at the same time mechanical accuracy in the dots, dashes, and spaces. By means of a "perforator," a slip of white paper is punched out after the following fashion:

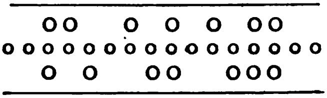

Fig. 40.

Three discs are struck by the punching clerk, the centre disc causing a punch to make the middle row of holes, while the left-hand disc produces the large holes placed vertically and the right-hand the pairs of holes placed diagonally.

In the second apparatus (the "transmitter"), the punched slip is used to regulate the passage of the electric current. The larger holes allow the passage of pins, which by means of a lever attachment regulate the making and breaking of contact. The action of the pins and the perforated slip has been compared to that of the cards in the Jacquard loom which regulate the lifting of the threads of the warp.

The pin passing through the upper hole causes a marking current to be sent, while the lower pin reverses the current and causes the mark at the receiving station to cease. In the case of the holes vertical to each other, the pins pass through almost simultaneously, so that only a momentary mark (a dot) is given. The time which elapses between the passage of the pins through the diagonal pair of holes permits a current to pass which marks a dash at the receiving instrument. Where a centre hole only occurs, no current passes, those holes serving only to move the paper through the instrument, and giving the necessary spaces between the marks. Many diagrams would be required to illustrate the mechanism of this beautiful instrument.

113. The "receiver" in which the message is printed, though different in detail, is the same essentially as the Morse instrument. The portion of slip figured above would produce the following marks at the receiving station :

- —   — -   — - -

a   *n*   *d*

The printing and spacing is done with a mathematical accuracy which hand-keying with the Morse cannot attain.

The speed of transmission depends on the length of line, the conditions of the atmosphere, etc., and the clockwork of both "transmitter" and "receiver" is furnished with means of adjustment to any speed not exceeding 120 words per minute.

114. The Wheatstone automatic instrument is used between all the principal cities in the kingdom, and one of its most successful applications is in the simultaneous transmission of news from London to a large number of towns. The highest speed is attained on the shorter circuits, and in the central office a punched slip is carried from one to the other of a series of "transmitters," called the "express news circuits," each serving several towns, so that an important speech in Parliament may be sent to thirty or forty towns in the space of a few minutes ! But for the aid of this valuable instrument, the enormous development of public and newspaper telegraphy within the last few years could not have been accomplished.

115. "*Duplex*" *Working.*—So far, the wire has been treated as a means of conveying signals in one direction only. But the possibility of sending messages in both directions simultaneously on one wire, has been long acknowledged by electricians, though only recently reduced to practical use.

The use of the ordinary phrase "an electric *current*" has rendered the fact of duplex working very difficult of comprehension to the popular mind. In point of fact, no current passes from one station to the other as is proved by the circumstance that two stations can exchange signals at one and the same moment. In "duplex" working, the electric force brought into operation by depressing the sending key is divided, one half passing to the line wire, and the other half going to "earth."

116. This object is accomplished by winding the coils of the Morse magnet in the same manner as in a differential galvanometer, splitting or dividing the out-going current into two portions, one passing to the line, the other passing to the earth through a resistance equal to that of the line. When the resistances are perfectly equal, the instrument is not moved by the out-going force.

When this has been effected, the instrument is only moved by signals sent from the distant station. The divided current presses equally on both sides of the sending instrument, and therefore leaves it unaffected. On reaching the distant station, the force affects the instrument at one side, and operates on it. If at the same moment the key at the other end is depressed, the force is divided there in the same way, one-half coming to the line wire. Those forces in the line wire neutralise or strengthen each other, as the case may be, changing the point of equilibrium to correspond with the signals sent from one end or both.

117. The duplex system was at first tried only on short circuits of 40 to 60 miles, but it is now successfully used over distances of 400 miles or more. The principle has been tried on other instruments besides the Morse, and is acknowledged to be a valuable addition to the capabilities of telegraphy.

118. *Submarine Cables.*—In 1850 the practicability of conveying an insulated wire under water was proved by the laying of a single copper wire, insulated with gutta-percha, between Dover and Calais, which continued in operation for one day. A heavier cable containing four wires was subsequently submerged at the same place, and continues in operation to this day. About 300 cables of various styles of manufacture have been laid in different parts of the world, varying from the three cables of 2000 miles each joining Europe to America, to the numerous short lengths which now unite the western islands of Scotland with the mainland. The cables laid in the earlier years were passed through

many vicissitudes, and have entailed great loss from imperfect insulation, mishaps in submersion, and other causes.

119. The Malta-Alexandria cable, laid in 1861, and which continued in use for eleven years, was the first long cable constructed with a careful regard to its electrical and mechanical conditions, and it corresponds very closely with the best form of cable now made. Its construction is shewn in the subjoined figure, which gives the cable full-size, in the different layers. C is a strand of seven copper wires, the strand being stronger and less liable to leakage, though less valuable as a conductor than a single wire of the gross diameter would be. This strand is laid in "Chatterton's compound" (tar, resin, and gutta-percha in certain proportions), and is insulated by three layers of gutta-percha with Chatterton's compound between each (G). Over this is a serving of tarred yarn (H) to act as a buffer for the core; and the outside (I) consists of a sheathing of eighteen iron wires to protect the cable from abrasion and give it the necessary strength. This cable was disused not from any inherent fault, but from the expense of maintenance caused by its being laid in shallow water.

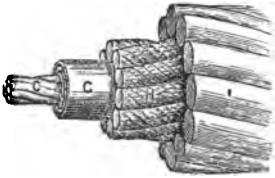

Fig. 41.

120. About thirty different forms of cable have been made, lighter cables being made for temporary use or for still water; while the heavier cables, carefully tested in every stage of manufacture and submersion, are intended for deeper and stormier seas.

121. In the longest submarine lines, it was found that only a weak current was received at the distant end, and in order to secure the action of the current, a more delicate instrument than any in use must be provided. This was found in the beautiful invention or adaptation by Sir William Thomson, of the *Reflecting Galvanometer*. The following figure shews the principle of this instrument.

In the figure, D represents a short magnetic needle, suspended by a silk fibre, and having attached to it a small mirror. Needle and mirror together weigh about a grain and a half. By means of a lamp, a pencil of light is thrown upon the graduated index, A B, a movement of this image

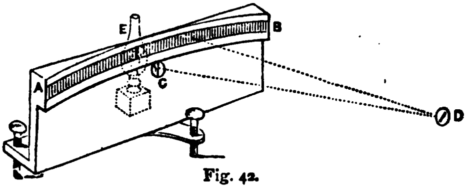

Fig. 42.

to one side or other being made to represent the dots and dashes of the Morse alphabet. To give steadiness to the suspended needle, it is brought to rest by a magnet after each deflection.

By an enlargement of the graduated scale some very delicate illustrations of electric action can be given. Thus, to shew that dissimilar metals, plunged in the same liquid, will evolve electricity, the wires leading to the galvanometer may be joined up to a steel knife and a silver fork, and on fixing the fork into a piece of raw meat, the light on the scale will be sensibly deflected at the instant the knife also is brought in contact with the meat. A "cell" consisting of a copper percussion cap with a small morsel of zinc has been found to create sufficient electricity to send a message across the Atlantic.

122. In his *Ink-recorder*, Sir William Thomson has given another beautiful adaptation of electric science. A fine coil is suspended between the poles of a fixed magnet, and attached to the coil is one limb of a small glass syphon, the other end of which dips into a vessel containing ordinary ink. So long as no current passes, the ink flows from the syphon in a straight stream, making a mark on a paper tape which runs below. But on the coil being attracted to either side by the passage of an electric current, the ink mark waves from side to side, the deflections serving as the dots and dashes of the Morse code.

ELECTRICITY OF CURRENT INDUCTION.

123. Faraday discovered, in 1832, that current electricity may be developed by induction, in a manner somewhat analogous to that in which statical electricity is induced. If a wire, whose ends are fixed in the binding-screws of a galvanometer, be laid alongside of another wire through which a current passes, there is an instant deflection of the needle. It soon falls back, however, to its original position, and not the slightest effect is seen so long as the current continues steadily to flow. On withdrawing the wire, or on stopping the current, we again have a deflection of the needle, but this time to the other side. As often as we join and break the current, we have these momentary flows of electricity induced in the galvanometer wire, which will set the needle a-swinging from side to side.

In general, then, it may be stated that the passage of a current in a conducting circuit produces a sympathetic electric state in a neighbouring circuit; so that *any change of condition* of the first is accompanied with a corresponding electric throb of the second. The effect on the galvanometer circuit will be greater the more rapidly we change the state of the inducing electricity, and the greater the extent of the second circuit influenced by the current.

124. We must note the directions of the induced currents. By the *approach* or *commencement* of the inducing or *primary* current, a wave passes in an *opposite* direction through the induced or *secondary* circuit; and by the *break* or *withdrawal* of the primary current, a wave passes along the secondary circuit in the *same* direction as that of the primary. Or, shortly, *at make and break of primary circuit, an inverse and a direct secondary current are respectively induced.* There is thus a great difference between current and statical induction. So long as the prime conductor of a machine is charged, it has a *constant* inducing influence on all bodies near it. But it is only a *change of tension* in current electricity which has any inducing power, and the power is momentary as the change.

125. *Induction Coil.*—The best form of inductive apparatus employed in practice is that known as *Rhumkorff's induction coil.*

Essentially, it consists of two bobbins or coils of insulated copper wire, an inner and an outer. The inner coil is of thick wire, and through it passes the primary or battery current. It is called the primary coil. The outer is of fine wire, and in it is induced the secondary current, at make and break of the primary circuit. It is called the secondary coil. Sometimes the inner coil is made so that it can be withdrawn from the secondary at pleasure.

The object of this coil-arrangement of the wires is to make each turn of the primary or inducing wire act not only on the turn of the secondary next it, but also on all the turns near it. A vastly greater effect is thereby obtained than if the two wires were simply laid side by side in a straight line. For this reason, too—that the strength of the induced currents depends on the extent of the secondary wire under the influence of the primary—very fine wire is used, to give as great a length of it as possible. Induced currents are of high tension compared with battery currents, and the fineness of the wire is no obstacle to the passage of the currents. Only, the finer the wire, and the higher the tension of the secondary currents, the more careful must be the insulation of the different turns and layers. Everything depends on the proper insulation of the secondary coil.

We have said that the wire of the primary coil is *thick.* This is to offer little resistance to the battery current, and to give the maximum of magnetic effect. For the inducing power of the primary increases with its magnetic power. In proof of this, it is found that the addition of a soft iron core in the primary coil increases enormously the strength of the induced currents; and this is because it heightens the magnetism of the inducing coil. In further proof of this fact, and in singular confirmation of Ampere's theory of magnetism, a permanent bar-magnet may be put for the primary coil. A current in one direction, or the reverse, is induced when it is put in or taken out of the secondary coil.

126. Such are the general features of the induction coil. Fig. 43 will give an idea of its appearance. The primary coil is inside and out of view, and the secondary, W, alone is seen. The ends of the secondary wire are soldered to two brass heads, P, P′, insulated on glass pillars, and carrying pointed brass rods, capable of universal motion. It is between these brass points that the induced current leaps across. The two battery wires are attached to the two binding-screws, *p* and *n*. Before reaching the coil, the current has to pass through, first, the commutator, C, and, second, a self-acting break not seen in the figure. With the commutator we can turn the current off or on, or reverse it at pleasure, by giving it a quarter or a half turn. The automatic break interrupts the current with extreme rapidity, and so gives rise to an incessant stream of induced currents.

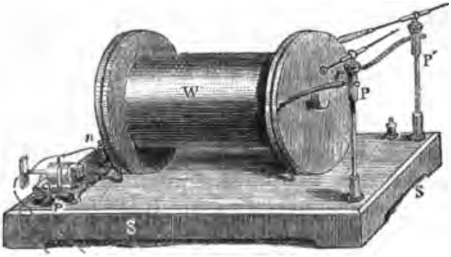

Fig. 43.

127. *Extra Currents.*—Not only does a current induce electricity in a neighbouring circuit, but it also acts inductively on itself. If we break a current passing through a *long* wire, we observe a bright spark at the part broken. This is very feeble if the wire be short, but very brilliant if it be long, and especially if it be wound in a coil. Obviously, it is not owing to the current being strong, for we know it is weaker the longer the path it has to traverse. The cause has been found to be due to *extra currents* in the wire, produced by the various parts of the wire circuit acting inductively on each other. They are *direct* when the current *stops*, and *inverse* when it *begins*. The effect of the

inverse current, induced in the circuit when it is joined, is to oppose and so retard the instantaneous passage of the main current; while the *direct* extra current, which follows the break of circuit, has a very weakening effect on the tension of the *secondary* current, if it is allowed to pass by spark or otherwise. This is because it has itself a very high tension, and it tends to prolong the current in the primary wire, and so impair the suddenness of the break, on which the tension of the induced current depends.

128. *The Condenser.*—This is an important addition to the coil, and serves to get rid of the extra current, which, as we have said, forms in the primary wire. It is placed in the sole, S, and does not meet the eye. It is simply a number of sheets of tinfoil separated by layers of oiled silk, the odd ones being all connected in one set, and the even in another. Each set communicates with an end of the primary wire, and acts like a coating of a Leyden jar. The whole, in some way or other not well explained, absorbs the extra current, and suppresses its injurious effects on the secondary current.

129. Some enormous induction coils have been made in recent years, the most powerful being one made for Professor Pepper. There are in it more than two miles of primary wire, and no less than 150 miles of secondary. The iron wire core alone weighs over a hundredweight, and the whole coil about three-quarters of a ton. It is said that with a powerful battery, a spark of fully two feet can be got from it.

130. The electricity of the induction coil is more of the nature of the frictional than of the galvanic excitement. The sparks which pass between the "points" are very like those of the machine, especially if the points be some distance apart. As with common electricity too, the physiological effects are very marked, and are a familiar object of exhibition. The beautiful luminous effects obtained by passing ordinary electricity through rarefied air or different gases, are shewn yet more brilliantly with the induction coil.

On the other hand, the induced current has little power to deflect a magnetic needle, or to effect chemical decomposition.

All this shews that the electricity of induction has enormous intensity or tension, and yet no great quantity; for we know that magnetic and chemical effects are due to electrical quantity only. In fact, the secondary current is as deficient in quantity as it is superior in intensity to the primary current.

MAGNETO-ELECTRICITY.

131. We have already seen that the action of the primary in induction coils may be exactly replaced by that of a magnet. The approach and withdrawal of a permanent magnet induces two powerful opposite currents in a coil. If, then, we had some means of rapidly removing the influence of the permanent magnet, as we had of the primary coil, by breaking its current, we should have induced electricity from magnetism, and altogether independent of galvanic batteries. To the immortal Faraday belongs the glory of the two discoveries of current induction, and of magneto-electric induction. In 1831-2, he first published, in the *Philosophical Magazine*, his researches on these two branches of the science of electricity.

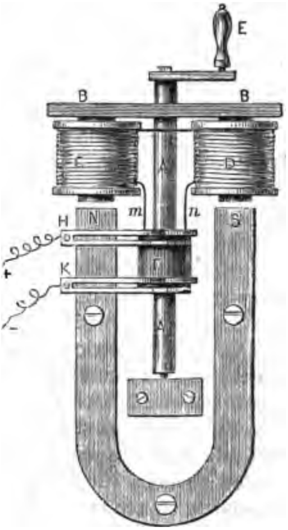

Fig. 44.

132. We shall now describe the usual mode by which such magneto-electricity, or magnet-origin electricity is obtained. Fig. 44 represents one of the simplest forms of magneto-electric machines. NS is a large fixed steel magnet, and BB is a bar of soft iron, which, with the pieces of soft iron under the coils C and D, forms a sort of bent armature to the magnet. Now, it is

evident that, as the armature turns round from being in line with NS, there will be first a gradual decrease of magnetic power in its cores, during a quarter of a turn, and then a gradual increase during the next quarter, till CD is again in line with NS. But the decrease of magnetic influence, or the withdrawal of it, induces a current in a coil; and its increase or approach induces an opposite current in a coil.

Thus, then, as CD turns round from the line of the poles, currents will be induced in the coils, if the two ends of the wire are joined. They will not be produced abruptly, but in a constant stream, as the change of magnetic influence is gradual; and during the first quarter of a turn they will be all in one direction. During the next quarter there is a gradual increase of magnetism in the cores, and this would produce currents in an opposite direction, were it not that there is also a change of poles. This double reversal, therefore, gives currents induced in the same direction as during the first quarter. So, then, during the first half-revolution from the line of the poles, a constant stream of currents is generated all in one direction. In the next half-revolution, the whole state of matters is of course reversed, and we shall have a current flow in the opposite direction. We have merely to introduce a commutating piece, F (which allows the springs, H, K, alternately to communicate with the ends, *m*, *n*, of the coil), to give us a constant flow of electricity in one direction. And by turning the handle we may get any amount of electricity we please, without any wasting of the machine, such as is in the galvanic battery.

133. With electricity obtained in this way, we may have all the ordinary current effects. Water may be decomposed, platinum wire heated red-hot, and soft iron magnetised. It has been much used for medical purposes, and the physiological effects are very powerful. Magneto-electric machines have also been used for firing gunpowder. Professor Abel has lately constructed fuses which may be readily fired with a pocket-machine of this kind.

Such a machine forms a link of the chain that binds all the physical forces together. The force of a magnet, and the force of a man turning a handle, may seem very different, and they do differ widely. Yet they differ only in *form*. With a suitable arrangement, the one form of energy may be as it were remoulded and brought forth in the shape of the other.

134. *Recent Magneto-electric Machines.*—The magneto-electric machine has now come into extensive use, as being a readier, steadier, and cleanlier source of current electricity than the galvanic battery. Very powerful machines have been constructed on much the same principle as that we have just described. They have been employed for the electric light in lighthouses, and are driven by small steam engines. We are to look upon them as simply the means of converting mechanical into electrical force or energy. But important modifications in the construction of these have been made in recent years.

135. *Siemens' Armature.*—In 1854 Siemens introduced a new form of armature, which brings the coil and its core nearer the poles of the inducing magnet or magnetic magazine. It has the wire wound *lengthways* or *parallel to the axis of its core*, and not across its length, as in common electro-magnets. The core is a cylinder of soft iron, with a large hollow scooped out on each side, leaving it somewhat like a piece of an iron rail. Insulated copper wire is wound along it till this hollow is filled up, and the cylindrical form restored. The *faces* of the core or rail, and not the ends, form the poles of this electro-magnet. It is not rotated *before* the poles of a steel magnet, as in the common machine, but *between* the poles of a series of magnets spanning it like a bridge, whose breadth is the length of the armature. A very rapid rotation can be given to the cylinder round its axis, and the iron faces are magnetised and demagnetised with corresponding rapidity.

136. *Wilde's Machine.*—Wilde of Manchester constructed in 1865 a magneto-electric machine of unequalled simplicity, which can be made to convert any amount of mechanical energy into electricity. All that is required is a little permanent or residual magnetism to start with as capital, and this is speedily worked up, on the compound interest principle, to any desired amount.

Wilde's machine consists of two magneto-electric machines, a small one surmounting a large one of precisely similar principle, but of enormously greater strength. The figure (fig. 45) represents an end view of the machine. In the small machine, the inducing power is a magnetic magazine, *m*, of twelve to sixteen steel horse-shoe magnets. It evokes currents in a Siemens' armature, which revolves between the poles, *a*, *b*, of the magnets, some 2500 times a minute. Two springs, connected with *n* and *p*, press on the commutator of the "Siemens," and are the poles of the upper current. This current is not used directly, but is sent through the coils, E, E, of the huge electro-magnet of the lower machine. It has a Siemens' armature, S, revolving between its poles, A, B, some 1800 times a minute. Both machines are precisely alike in action, and differ only in power. The armatures are both driven by belts from the same shaft. The arrangement of the magnetic poles is very ingenious. It is the same in both, but we shall refer only to the lower. They consist of two masses of soft iron, A and B, hollowed out so as to form the two sides of a tube to enclose the Siemens' armature. Pieces of brass, L, L, serve to insulate the two poles magnetically, and to complete the tube. This protects the armature from the resistance of the air, and brings it as near as possible to the inductive influence of the poles.

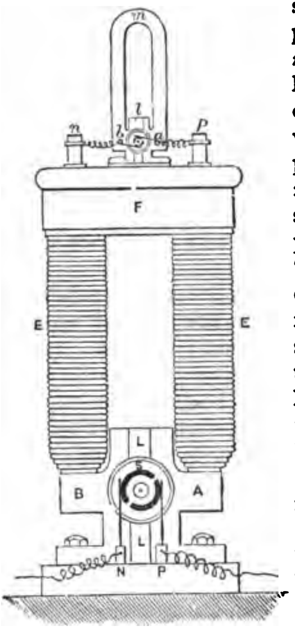

Fig. 45.

137. The effects which this machine is capable of producing are almost incredible. When worked with a three-horse-

power engine, the current of the second armature consumes carbon sticks three-eighths of an inch square, and evolves a light of insupportable brilliancy. With one that consumes carbons half-an-inch square, a light so intense is got that, when put on a lofty building, it casts shadows from the *flames* of street lamps, a quarter of a mile away. Mr Wilde succeeded in melting an iron rod fifteen inches long, and a quarter of an inch thick. Wilde has even employed the current of the second armature to magnetise a second electro-magnet still more powerful than the first. The whole required a fifteen-horse-power engine to drive it, and the heat of the current was sufficient to melt a platinum bar two feet long and a quarter of an inch thick. Indeed, the only limit to the amount of electricity which might thus be obtained, is the mechanical energy required to be expended.

138. Several modifications of Wilde's principle have been introduced within the last few years by Siemens, Wheatstone, Ladd, and others. Ladd's improvement makes the machine more convenient and simple in form, and promises to make it more popular. Theoretically, these machines are examples of the mutual convertibility of heat or mechanical energy into kinetic electric energy, and of this again into the energy of mechanical force or of heat and light.

THERMO-ELECTRICITY.

139. As the electric current produces heat, so we may invert the order of the phenomena, and from heat derive electricity. When any two metals, unequally susceptible to heat, are soldered together, and heated at the joining, an electric current is evoked. The two metals which shew this property most readily are *antimony* and *bismuth*. Thus, if a bar of antimony, A (fig. 46), be soldered to a bar of bismuth, B, and their other ends connected with a galvanometer, G, a current will pass when we heat the junction, S. Inside the couple, it flows from bismuth to antimony, and outside from antimony to bismuth, as we know by the side to which the needle swings. If any two of the following

metals be joined in this way as a thermo-electric pair, a current will flow *at the heated junction*, from the one which occurs first in the list to the other—*bismuth, nickel, lead, tin, copper, platinum, silver, zinc, iron, antimony, tellurium.* This is the order for these metals, all supposed at the same mean temperature, and that not over 70° F. In most cases the thermo-electric power of a pair of metals varies considerably when anything like high temperatures are reached.

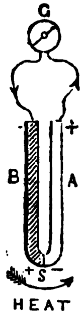

Fig. 46.

If *cold*, instead of heat, be applied at the junction of two metals, it will produce a current opposite in direction to what heat would. When we plunge the antimony-bismuth couple in ice-water, a current flows *from bismuth to antimony* in the outside wire.

140. *Thermo-Electric Battery.*—One antimony-bismuth pair has little power, but several may be joined, just as in a galvanic battery. Fig. 47 shews the arrangement of such a thermo-electric pile or battery. Obviously, only the odd junctions must be heated, for if all were, there would be no current at all. The current is from bismuth to antimony when a junction is heated, and from antimony to bismuth when it is chilled. Thus the strength of current produced will depend on the difference of temperatures in the two sets of faces. A pretty strong current may be evolved by keeping one set of junctions in ice, or a freezing mixture, and the other in boiling water. The electro-motive force is, however, very weak compared with that due to chemical action. In fact, it takes about one hundred and fifty bismuth-antimony pairs to give the electro-motive force of a single Daniell cell, one set of joints being kept at the freezing, and the other at the boiling point of water. For this reason, heat is not available as a convenient direct source of electricity by any of the means yet discovered.

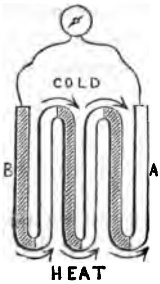

Fig. 47.

141. *The Thermo-pile.*—It is as a thermometer that the thermo-electric battery has its most important application. When employed for this purpose, it is called a *thermo-pile.* To form it, some twenty or thirty antimony-bismuth pairs are connected as in a battery, and compactly put together with varnished paper between the sides. The whole is enclosed in an insulating tube, so that only the junctions are exposed at each end, and these are blackened, to increase their absorption of heat. Wires connect the end plates with an astatic galvanometer, whose coil must be of *short thick wire*, on account of the feeble tension of heat-excited currents. If either face be heated, a current will arise: if one be heated, and the other cooled, the current will be stronger; but if both be heated alike, there will be no current. So sensitive is such an instrument, that the mere approach of the hand or of a piece of ice, though at a considerable distance, is sufficient to deflect its galvanometer needle. For experiments on radiant heat, this instrument is most important, and now supersedes all others.

142. A curious effect was observed in 1834 by Peltier, and is sometimes known as the *Peltier effect.* When a feeble galvanic current is sent through an antimony-bismuth pair, in a direction from bismuth to antimony, and the junction is immersed in water, cooled down to the freezing-point, but not frozen, as much heat will be absorbed at the junction as will make the water freeze. Heat will be produced if we reverse the current, and the water will not then be frozen. In a series of pairs the junctions will be alternately heated and chilled. Only the current must not be too strong, else the whole will be heated.

143. All these facts have been shewn to be in complete accordance with the modern doctrine of the conservation of energy. If the two faces of a thermo-pile be kept each at a constant temperature, a constant current flows, in the antimony plates, from the warmer junctions to the other; and the energy of the current is an exact equivalent of the excess of heat-energy absorbed at the warmer over that given out at the colder junctions. If the current be not converted into magnetical, mechanical, or chemical force, the heat energy will be

entirely recovered as heat distributed through the circuit. But if the current be used to do any work, a corresponding amount of heat will be withdrawn from the circuit.

ANIMAL ELECTRICITY.

144. The tissues and organs of animals are not only affected by the electric spark and current, but they are themselves also a source of electricity. In general, the strength of their electro-motive power is so feeble that it requires special experiment to detect it. There are, however, some species of fishes which exhibit such a power very readily.

145. *Electrical Fish.*—It was long ago known that a kind of flat fish, found on the shores of the Mediterranean, produced a numbing sensation in the arms of the fishermen when they handled it. The Romans called it *torpedo*, from a word meaning to "benumb," and this name is now usually given to the whole genus to which it belongs. It has regular electric organs or batteries, placed on each side in the spaces between the pectoral fins, the head, and gills. Each battery consists of a number (varying according to age) of hexagonal prisms, somewhat like the cells of a honeycomb. The double set of organs is completely under the control of the torpedo; it can give a shock similar to that of a Leyden jar; and Matteucci has even obtained sparks from it.

Among other kinds of fish with a similar power, the most noted is the *Gymnotus electricus*, or electrical eel, found in the rivers of Bengal and Surinam, and common in all the streams flowing into the Orinoco. It is from three to four feet in length usually, though it has been found even six feet long. The whole of its viscera and digestive organs lie near the head, the rest of the body being taken up with the electrical apparatus. This consists of four batteries—two on each side, and placed one above the other, the upper being the larger. The batteries are made up of a number of piles, looking very like galvanic troughs, and numbering from thirty to sixty in the upper, and from eight to fourteen in the lower battery.

Faraday experimented, about 1840, on a specimen of this eel, exhibited in the Adelaide Gallery, in London. The shock which the animal was capable of giving was very great, equal to that of a good-sized Leyden battery. It was strongest when one hand communicated with the head, and the other with the tail, and it was sufficient to stun or even kill smaller fish.

146. In all such cases we have the extreme of electric development in the animal system. But apart from special organs, living nerve and muscle have an electricity of their own, which fails as life dies out, and is wanting altogether after death. Much attention has been given of late years to this electricity of muscles and nerves; and the discoveries of Du Bois-Reymond, Matteucci, and others, have given the study a title to be regarded as a branch of physical science.

147. Galvani must, however, be credited with being the father of the science. Frog-limbs, as prepared by him, are still one of the best means of shewing not only the effect of galvanic action on the animal frame, but also the existence of an electromotive force in the frame itself. Galvani proved that two metals in contact are not required to cause convulsions in the frog-limbs. A single wire joining the spinal nerves with the muscles of the leg causes sensible convulsions, and he argued from this the existence of muscular and nervous currents.

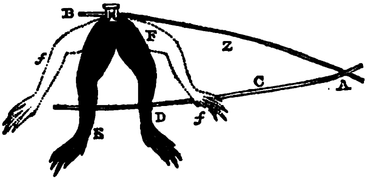

Fig. 48.

The existence and principal laws of such currents are now beyond a doubt; though we are still in darkness as to their real origin, and their analogy to other known sources of electricity.

In living animals, or in those very recently killed, there is always a current flowing from the interior of a muscle or of a nerve to its surface. These currents cease in warm-blooded animals in a few minutes after death; but in cold-blooded animals, such as the frog, they continue for a much longer period.

148. That there are natural electricities resident in the nerves and muscles to cause these currents, may be shewn by a delicate galvanometer, or by the quadrant electrometer of Sir W. Thomson. By means of this sensitive electrometer, it is found that the surfaces and the ends of nerve (or muscle) fibres are oppositely charged like the two coatings of a Leyden jar. The sheaths of the fibres are supposed to be such bad conductors that they can act as a dielectric, like the glass of the Leyden jar. A charge is given to the outer surface by oxygenation, or in some other way, and an opposite charge is induced by it on the inside. The current that affects the galvanometer arises from the connecting two oppositely charged parts.

149. But the curious thing is, that the muscle and nerve fibres are *charged*, while they remain *at rest*, and *action* is accompanied with a disappearance or *discharge* of the electricities. This is like the discharge which occurs when the torpedo puts itself in action. Indeed, the discharge of the torpedo may only be "the unmasked form of what occurs in a masked form in every case of muscular and nervous action."

As, then, a natural activity of nerve and muscle coincides with natural electric discharges in their tissues, so an artificial activity is induced by artificial discharges. Mere charge or electrification has no effect, so long as it is constant. It is only a *sudden change of charge* (which is really a discharge) that produces an involuntary and artificial activity.

This explains why the passage of a voltaic current is attended with no artificial production of action so long as it is constant. It is just equivalent to a constant charge of the fibres, and, therefore, to a state of rest. Only at the letting on or taking off of this charge do we have a change of state, which is really a discharge; only then do we feel the *shock;* and only then are the fibres excited. This is easily verified by experiment with the galvanic current, either on the living body, or on the bodies of animals recently dead.

150. The physiological effects of electricity were among the

first observed, and had doubtless a good deal to do with the rapid development of the science. The life-like convulsions excited by it in the limbs of dead animals hinted that nerve-force might be nothing but electricity. Many experiments were made on the bodies of oxen, horses, sheep, and such like, soon after death. Executed criminals even were experimented on, and many of the vital actions were alarmingly induced. All this was to find the connection between vital and electrical force. It was clear there was some relation, and it was thought probable that the two forces might be identical.

Experiment has, however, failed to establish any relation between electricity and life so definite as it has established between electricity and the physical forces of heat, light, chemical, magnetical, and mechanical force. Man would fain find out the secret of life, and the panacea for all his infirmities. But the problem remains, and is likely to remain, unsolved.

ELECTRIC POTENTIAL.

151. In place of the general term electrical state or condition, the more precise term *potential*, which was at first employed by mathematicians only, is now coming into common use among practical electricians. It is derived from the modern all-embracing doctrine of *Energy*, which connects the various forces of nature in one common chain by one common nomenclature.

Energy of any sort, whether mechanical, thermal, magnetical, or electrical, is the power of doing *Work*, that is, of overcoming resistance of some kind, and is measured by the amount of a known and definable resistance that it is capable of overcoming. A moving mass has, in virtue of its motion, a power of combating resistance, as, for example, a waterfall, a flying bullet, a rotating fly-wheel, etc.; and the work-power is greater the greater the mass and the greater the velocity. This is apparent, visible, actual, or *Kinetic Energy*. But, again, a stone raised to a height, or a head of water, has Energy in virtue of its elevation above the common surface of the earth. In this case nothing is seen; the Energy is latent, possible, or *potential* merely, though as real as in the former case; and the Work-power depends on the quantity of matter so raised, and the height to which it is raised. It is measured by the amount of Work that it can do in its fall, or by the amount of Work expended in raising it against the force of gravity. The power which the stone or water, when raised, has, in virtue of its separation from the earth, may be called its difference of *gravitation potential*, and is the same by whatever means it may have been produced. So by friction, chemical agency, heat, or magnetic influence, an electrical separation, or difference of electrical potential is produced in dissimilar substances. The *quantity* of electric Energy so called forth, will depend on the extent of the electrified surfaces, and on the height of the electric potential, above that of the common reservoir or level, the earth, just as the *quantity* of gravitation Energy depends on the mass, and the degree of elevation above the ground.

152. To estimate the quantity of Energy in any case, suitable units of measure must be agreed on. The unit quantity of electricity is that quantity which would exert upon a similar quantity the unit of force at the unit of distance. The Committee of the British Association on Electrical Standards, adopted as their unit quantity, that which would repel an equal quantity at a distance of one centimètre, with such a force, that in one second it would cause one gramme of matter to move at the rate of one centimètre per second. The apparatus which would so measure or express any electrical forces, is called an *Absolute Electrometer*, in contradistinction to ordinary electrometers, which merely indicate *difference* of electrical potential.

153. The analogy of electricity to a fluid in its behaviour, on which are based all the old and common terms of the science, also obtains here. There is always a transference of electricity from a body at a higher, to one at a lower potential; just as there is a flow of liquid only from a higher to a lower level. For the measurement of this level we assume as our zero of reckoning, the condition of the earth

around us: a body is positively or negatively electrical according as its potential is higher or lower than that of the earth around it; just as the height of a body may be considered positive or negative according as it is above or below the mean sea-level in its vicinity. On uninsulating a body therefore (or on connecting it with the earth), there is a flow or transference of electricity from the body to the earth, if it is positively electrified, and from the earth to the body if it is negatively. The analogy between electric and fluid Energy is very complete. We have kinetic electrical Energy in the galvanic current, because we have there a continuous *electrical fall* owing to the difference of electric level or potential in the two plates; and a mere difference of electric level cannot perform Work any more than a mere head of water, without provision for its continued fall in a stream or current.

A charged Leyden jar or battery bears the same relation to a charged galvanic battery as the pressure of a head of water in a hydrostatic bellows bears to the pressure in a pipe leading from a cistern filled with water. The tendency to uniformity of the liquid level in the former case, may require a very much greater pressure to prevent it than in the latter, but the fall to a uniform level occupies only a short time, and is of little value for turning a wheel or doing other such work as the steady current can effect. So with the electric pressure, tension, or potential. In the Leyden jar or battery, a very great distance, resistance, or insulation, is needed to prevent assimilation of the electric level between the interior and the exterior coatings; whereas the slightest break of contact in the galvanic battery suffices to keep the electric Energy pent up. Hence the practical value of the galvanic condition of electrical Energy compared with the statical.

154. Induction is the disturbance of the electrical level or potential on a conductor, and can only be caused by the presence of a body at a different potential or level, a rise of the level at one side being accompanied by an equal depression at the other; or, in the common phraseology, equal quantities of positive and negative electricity being produced at the same time.

155. Bodies, from some unexplained physical cause, appear

to have each their own peculiar electrical level with respect to that of the earth ; so that when two different metals are placed in contact, a difference of electrical potential is set up between them, and the galvanic battery is an arrangement for producing an accumulation of such differences of potential, with the means of their constant renewal as the electricity passes from a higher to a lower level.

156. Electricity in its passage from a higher to a lower potential, may be transformed into any of the other forms of Energy according to circumstances. If it pass along a wire, it may appear as heat vibration among the particles of the wire, or it may be transformed into magnetic attraction or repulsion, or by that means into mechanical Energy. In accordance with the modern theory of the Conservation of Energy, whatever amount of Work-power is used in any part of the galvanic circuit, either in the shape of heat, or of magnetism, is just so much abstracted from the electrical Energy of the current, as indicated by a galvanometer.

For anything like a comprehensive or clear idea on this important doctrine of electric potentials, there is no scope in such a treatise as the present, and reference must be made to larger handbooks, such as Deschanel's "Natural Philosophy" (by Everett), Part III. ; Fleeming Jenkin's "Electricity and Magnetism ;" Balfour Stewart on the "Conservation of Energy ;" and, for those who understand the higher mathematical analysis, to Professor Clerk Maxwell's work, "Electricity and Magnetism," or Sir W. Thomson's "Papers on Electrostatics and Magnetism."

QUESTIONS.

Sections 1, 5. Given a bar of soft iron, a bar of steel, and a loadstone, state how you would detect the steel.

2, 4. Describe some experiments by which the laws of magnetic polar action may be verified. State those laws.

5. Explain the attraction of soft iron by a magnet on the theory of induction.

6. What is the object of the horse-shoe form commonly given to a magnet? Why should a magnet never be left without its keeper?

7, 8. How would you best magnetise a strip of steel? Is there a limit to the magnetic strength that you could communicate?

9. Give a short account of any of the ordinary theories of magnetism.

10. Explain the terms "*diamagnetic*," and "*paramagnetic.*" Name any diamagnetic substances.

12. If you were to sail from London to Australia, what differences would you expect to find, along your course, on the indications of the ship's compass?

14. What are the *magnetic elements* at London at the present time, and what changes on them may be looked for a hundred years hence? How is the "*dip*" of the needle accounted for? What is an isoclinic chart?

15. How is the *intensity* of the Earth's magnetism measured? Is it the same all over the globe?

16. Is there any reason to believe that any of the heavenly bodies are magnetic? Why are a workman's tools usually magnetised?

18. Describe how you would shew experimentally that there are two kinds of electricity, and that they follow the laws of magnetism in their mutual action. Why are the terms *electric* and *non-electric* no longer employed? What are used instead?

19. Explain distinctly what is meant by *positive* and by *negative* electricity. What were the old terms?

20. State briefly the four leading laws of electrical development.

21. State briefly any of the common theories of electricity.

22, 23. Compare the phenomena of magnetic and electric induction, pointing out any differences that occur to you. How may a body be charged permanently by electric induction?

24. What peculiar effect has the shape of a body on the distribution of its electricity?

26, 27. Supposing you wished to have an electrical machine made, what materials would you require, and what instructions would you give to a non-professional instrument maker? What are the respective advantages of the cylinder and the plate machine?

28. Describe the electrophorus, and explain the principle of its action. Is it a source of indefinite electrical power?

29. Give a descriptive sketch of Holtz's machine; and describe any experiments you could shew with it.

32. How may the Aurora Borealis be artificially imitated? What explanation of the phenomenon does this suggest?

34. In what way is a gold-leaf electroscope used to detect the nature of the electricity in any body?

36, 37. Describe Coulomb's Torsion Electrometer, stating the laws of electric action demonstrated with this instrument.

40, 41. If you charged a Leyden jar by holding the knob, and presenting the outer coating to the prime conductor, what would be the effect of your setting the jar on an ordinary table, or on the ground? Why?

42, 43. How would you construct a battery of Leyden jars? and what electric effects might be shown with it?

45, 46. To what causes are thunderstorms ascribed? What resemblances does lightning bear to an electric spark?

47. Why should one avoid being under a tree, or near a damp wall, in a thunderstorm?

50, 51. State generally the difference between Volta's and Galvani's theory as to the source of electric energy in the pile.

52. A strip of silver and one of pure zinc are dipped in acid water: state what occurs when they are kept apart, and what effect making them touch has.

53, 54. Explain, on the chemical theory, why gas bubbles appear at one of the plates of a galvanic pair. At which of the plates must they be looked for in a gold-iron pair? What do you understand by galvanic *circuit* and *current*, by direction of the current, and by electromotive force?

54. Give the general law connecting the relative oxidability of metals with their behaviour as galvanic couples.

55. Is it wise to fasten zinc roofing with iron or copper nails, and why?

56. How does the electricity of the pile differ from that of the friction machine? Give an analogous difference in the case of heat.

58. How is polarisation of the plates of a battery to be explained, and how obviated? How is *local action* to be avoided?

59, 60. Describe the simplest form of copper-zinc battery. What are its faults?

62, 63, 64. Explain the principles of action of a Daniell, a Grove, and a Bunsen cell; stating their respective virtues.

66, 67, 68. What are any of the modern modifications of the Daniell battery, devised for the sake of economy?

69, 70. Give an account of the *sulphate of mercury* and the *Leclanché* batteries, and the theory of their action.

71. What is Ampere's rule for connecting the direction of a galvanic flow with the side to which it swings a magnetic needle?

73. Describe generally the principle of the astatic galvanometer. Should the needles be *perfectly* astatic? Why?

76. Explain exactly the distinction between the strength of a *battery* and of *a current.* Under what circumstances may a single couple give as strong a current as a large battery?

77. If a strong battery current were passed along a chain, whose links were alternately gold and aluminium, how would the distinction between the two metals appear? Why?

78, 79. What are the effects of the galvanic current on the different human senses?

80. How is the electric light obtained? and what are the chief obstacles to its common use?

81, 82. Explain the terms, "*electrolysis*," "*electrode*," "*anion*," "*anode*." Why is it impossible to decompose water with a single pair of galvanic plates, however large they are?

83. What is the principle and the value of Faraday's voltameter?

85. Explain generally the process of taking an electrotype cast in copper off a wood engraving.

87. What is Ampere's theory of magnetism? What are the laws of current action on which it is built?

88. Supposing that we wind a wire from a battery round (1.) an iron bar, (2.) a steel bar, and (3.) a copper bar, what occurs in each case?

89, 90. Describe the construction and advantages of an electro-magnet; and give any practical applications of electro-magnetism that suggest themselves to you. Why is soft iron used for the core of a magnet? *Why is iron used at all?*

90. Is there any hope that electricity may replace coal as a source of motive power for our engines? Why?

92, 93. What is meant by an "*earth*" in telegraphing? Sketch the course of the electric current from its source at the battery to its "*earth*" at the next station.

95. Describe the instrument which makes the clicking sound heard when a telegram is being sent.

96, 97. Describe the principal parts of the "*Morse*," and explain the object and connections of the "*relay*."

100. Explain generally the principle of the Morse code of signals.

104. How may a message be sent to a hundred different places at the same time?

105. Give a general idea of the Hughes type-printing telegraph; on what does the efficiency of the whole depend?

106. What is the principle of the single-needle telegraph, used on the railway lines?

107. Describe the Wheatstone A B C, or dial indicator.

108-110. What are acoustic telegraphs? and name any of their advantages.

111-114. Explain the principle of Wheatstone's automatic transmitting apparatus, stating its advantage over the hand system.

115, 116. How is it possible to use the same wire for simultaneous messages in contrary directions.

119. Give a sketch and short account of the construction of a submarine cable.

121. What sort of indicator is employed in the case of the Atlantic telegraph? Why is an ordinary one useless here?

122. Give a short account of the instrument by means of which messages sent from America may be made to record themselves in ink here.

123, 124. How would you most simply exhibit the phenomenon of current induction? What are the laws connecting the relative directions of the inducing and induced currents?

125, 126. Explain the "make" of the *primary* and *secondary* of an induction coil; and state what precautions as to insulation are necessary.

127, 128. What is meant by the extra currents of a coil apparatus? What are their effects? How are these counteracted?

130. What is the nature of induction-coil electricity? and what effects is it best adapted to shew?

132. Describe the construction and principle of the common magneto-electric machine used for medical purposes. Why are its shocks so disagreeable?

135. What is the peculiarity of Siemens' armature for the magneto-electric machine.

136, 137. Sketch and describe shortly *Wilde's machine*, with Siemens' form of armature. Mention some of the effects it can produce.

140, 141. Distinguish between a thermo-electric battery and a thermopile. Is heat available practically as an economical source of electric currents? How?

142, 143. What is meant by the *Peltier effect?* How does it accord with the modern doctrine of Energy?

145. On what grounds are some kinds of fish named specially electrical?

147, 150. What part is it supposed that electricity plays in the muscular action of every animal during life?

151. What is a more precise term for electrical state? What doctrine is it derived from? What is Energy? Give instances. How may a difference of electric potential be produced in dissimilar substances? What does the quantity depend on?

152. How is the quantity measured? What is the British electrical unit? What is an Absolute Electrometer?

153. How does electricity flow? What is the zero of high and low in electric potentials? When a body that has been insulated is connected with the earth, what takes place?

154. Describe induction in terms of the potential.

155. How does contact of two different metals produce electrical disturbance?

156. What may happen to electricity in its passage from a higher to a lower level? If a galvanic current heat the conducting wire, is it as strong as before? Why?

THE END.

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